CHAPTER 7

ELECTRICAL APPLIANCES, TEST EQUIPMENT, MOTORS, AND CONTROLLERS

In this chapter we will discuss the installation, principles of operation, troubleshooting, and repair of electrical appliances, motors, and controllers. We will also discuss the principles of operation and use of test equipment. Some of the appliances that we will discuss are washing machines, clothes dryers, electric ranges, and hot-water heaters. No matter what type of command you are assigned to, whether it be a mobile construction battalion, public works, or construction battalion unit, you, as a Construction Electrician (CE), will be called upon to install, troubleshoot, and repair various appliances.

The information on various representative appliances applies generally to a number of different makes and models. You can use the repair procedures for other appliances that you will service. To troubleshoot and repair appliances effectively, you must understand the principles of operation that apply to them.

Throughout this chapter you will see references to the National Electrical Code© (NEC©). Look up each article and read it. More specific information is contained there than will be discussed in this chapter. You will need this specific information to do your job properly.

Appliances are of three types: fixed, portable, and stationary. Fixed appliances are installed at a specific location. Once installed, they become permanent. Examples of fixed appliances are hot-water heaters and central air-conditioning units. Portable appliances can be moved from place to place. Examples of these are food mixers and toasters. Stationary appliances are not easily moved from place to place in normal use. Examples of these are window air-conditioning units and refrigerators.

The components of appliances range from a simple ON/OFF switch to more essential components, such as motors, pumps, and temperature control switches. There are components in similar appliances that work on the same principle and, in many cases, the majority of the parts from one type of appliance can be interchanged with another. The only difference in many appliances is the housing and brand name. The important point to remember is when a particular brand name appliance is inoperative because of a broken component, you may be able to use a component from another brand name appliance to get the appliance back into operation.

APPLIANCE INSTALLATION REQUIREMENTS

Many factors affect the installation of appliances. We will discuss some of the more important of factors in this section, to include; connection to power, means of disconnection, branch circuits, and installation by type of appliance

Generally, appliances may be connected only to a receptacle with the same rating as the appliance. A standard 110-volt, 15-ampere duplex outlet may supply a single 15-ampere fixed or a 12-ampere branch circuit. On new construction projects all 15- and 20-ampere receptacles must be of the grounding type. (Refer to NEC©, Article 250.) Most household appliances, such as toasters, flat irons, waffle irons, refrigerators, and portable ovens, are rated at less than 12 amperes, so they may be used in the standard outlet on a 110-volt, 15-ampere circuit.

Each appliance should have a means for disconnection from all ungrounded conductors. Since there are different types of appliances, naturally there are different disconnecting means.

For fixed or stationary appliances that are not rated 300 voltamperes or 1/8 horsepower (93.3 watts), the branch-circuit overcurrent device can serve as the disconnecting means. For an appliance rated greater than 300 voltamperes or 1/8 horsepower (93.3 watts), the circuit breaker may serve as the disconnecting means if it is within sight from the appliance or is capable of being locked in the open position. On portable appliances, an attachment plug and receptacle may serve as a disconnecting means; this disconnection arrangement may include household ranges and clothes dryers. The amperage rating of the receptacle should not be less than the rating of the appliance, unless so authorized by the NEC©. Attachment plugs and connectors should conform to Article 422 of the NEC©.

Unit switches that are part of an appliance that disconnect all ungrounded conductors are permitted as the disconnecting means. Refer to Article 422 of the NEC© for other means of disconnection on the various types of occupancies. When you are grounding an appliance, refer to the NEC©, Article 250. Any part of an appliance that may be energized must be grounded except for those mentioned within this article.

SMALL APPLIANCE BRANCH CIRCUIT

A circuit that supplies electrical energy to one or more outlets to which appliances are to be connected is called an appliance branch circuit. These circuits are not to have any permanently connected lighting fixtures that are not a part of an appliance.

The NEC© states special requirements for appliance branch circuits. We will go over a few of these requirements.

In dwelling occupancies, small appliance loads, including refrigeration equipment, dining areas, kitchens, family rooms, pantries, and breakfast rooms, should have two or more 20-ampere branch circuits installed (referred to as special-purpose outlets) in addition to the branch circuits previously mentioned. These circuits will have no other outlets except for clock outlets.

At least two appliance receptacle branch circuits will be installed in the kitchen for receptacle outlets. In the laundry room at least one 20-ampere branch circuit will be provided. Again, always refer to the NEC© before installing any circuit or equipment to ensure you have the proper number of circuits needed and the correct size wiring and disconnecting means necessary for each branch circuit, appliance, and piece of equipment that you are to install,

TYPES OF APPLIANCES

We will discuss various appliances that you will encounter throughout the Naval Construction Force (NCF). You may be called upon to install, troubleshoot, and repair all appliances mentioned here, plus others not covered within this chapter.

Washing Machines

The purpose of a washing machine is to clean clothes by forcing a mixture of water and a cleaning compound through the clothing regardless of how the machine is constructed.

Washing machines can be classified in various ways, but generally they are divided into the agitator and tumbler types. Each type has advantages over the other and may have certain disadvantages, but each will give years of service if properly operated and maintained.

COMPONENTS.—Before attempting any troubleshooting or repairs, you have to understand the components of the washer and their functions. Washers vary in construction, but their operating principles are similar.

Electrical Supply.—Before connecting any washer to a power source, look at the motor nameplate or the manufacturer's manual to determine the correct electrical supply for the washer. Normally, a 120-volt, 60-cycle, 15- to 20-ampere circuit is required. Most machines come with a three-prong power cord that is to be inserted into a grounded duplex convenience outlet according to NEC© requirements. UNDER NO CIRCUMSTANCES SHOULD YOU REMOVE THE GROUND PRONG FROM THE PLUG. This prong is a ground that protects the user from electrical shock and possible electrocution.

Timer.—The timer is the heart of the electrical system. It has a motor, an escapement, and multiple-circuit cam switches, all assembled into one unit. The timer (being a synchronous type of motor, like those in clocks) has a small pinion gear that drives the escapement. The escapement is a spring-powered mechanism that advances the time interval. The motor winds up a spring that unwinds abruptly to advance the camshaft the correct number of degrees. A ratchet mechanism in the escapement output gear permits the timer to be advanced manually. The camshaft opens and closes smaller switches in the multiple-circuit cam switch case. These switches control the operation of the washer. All electrical circuits come through the timer. The main ON/OFF switch, operated by a push-pull action of the timer shaft, also is located within the timer housing.

Motor.—The most essential component of a washer is the motor, which is usually a 1/3-horsepower, 120-volt unit. The motor supplies the power that operates the agitator, spins the tub, and operates the water pump. The motor is protected by a thermal overload protector connected in series with both the main and starting windings. The overload protector opens if the windings overheat. Some washers are equipped with two-speed motors and others have reversible motors.

Belts from the motor to the transmission drive the agitator and the tub. Figure 7-1 shows a typical washer

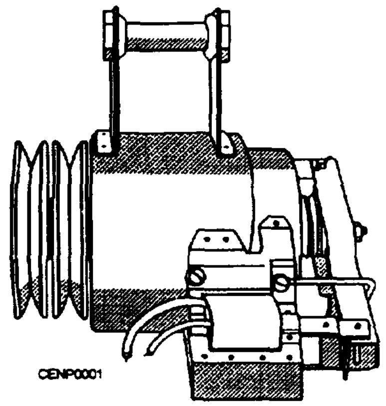


Figure 7-1.—Typical washer motor.

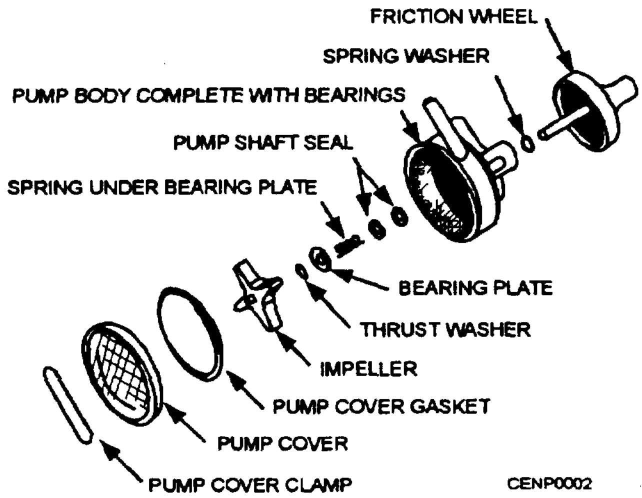


Figure 7-2.—Pump assembly.

motor with pulleys, mounting bracket, and high-speed solenoid.

Pump.—The pump removes water from the tub after each cycle. Normally, the pump is located next to the motor and is engaged by the electrical solenoid. The solenoid engages the friction wheel of the pump (fig. 7-2) with the friction wheel on the motor, causing the shaft to turn the impeller and extract water from the tub. The discharge hose of the pump must be mounted above the water level of the tub, or the water will dram without the operation of the pump. In some cases, the pump is belt-driven and the solenoid tightens the belt to make the pump operate.

One of the major causes of pump failure is foreign objects lodged in the pump impeller. To correct this situation, you remove the cover clamp (fig. 7-2) and the cover and remove the lodged item from the pump. Other causes are slippage between the friction wheels of the pump and motor and failure of the solenoid. Also, check for clogged hoses leading to and from the pump.

Inlet Valves.—Water inlet valves equipped with two solenoids are called mixing valves. They have two water inlets: one hot and one cold. They actually mix hot and cold water. When the temperature control switch is set in the HOT position, the solenoid on the hot-water side of the valve is energized. That permits only hot water to enter the machine. Conversely, when the temperature control switch is set in the COLD position, the solenoid on the cold-water side of the valve is energized, and only cold water is permitted to enter. Positioning the switch in the WARM position energizes both solenoids, allowing hot and cold water to mix.

When water fails to enter the machine naturally, check the water supply first. Then check the screen at the inlet valve. At the hose connection to the inlet valve, there is a fine screen: make sure it is free of any foreign objects. Ensure that you have power to the inlet valve solenoid. Remember the electrical power must come through the water-level control switch, water-temperature selector switch, and timer.

As a last resort, disassemble the valve and check for foreign objects. Also, ensure that the plunger inside the valve is free to operate; there must be at least 10 pounds of water pressure to overcome the spring pressure of the plunger in the solenoid valve.

Water-Level Switch.—The water-level switch, normally actuated by pressure, controls the amount of water that enters the tub. The switch has an adjustment screw to set the level of the water. The tighter the screw, the more pressure is required to operate the switch, and the higher the water level required The water-level switch has two sets of contacts, one normally opened and the other normally closed. As the correct water level is reached, the switch opens one set of contacts, de-energizing the water fill valve. The other set of contacts closes and completes a circuit to the timer, allowing the timer to operate and start the next cycle. The timer will not operate during the fill cycle.

Safety Switches.—Most washers have at least two safety switches. One is an off-balance switchthat opens a circuit to the motor if the clothes shift to one side. Moving the tub to the center and rearranging the clothes will close the switch, allowing the washer to operate. This switch prevents damage to the machine from the vibration of operating with an unbalanced load The other safety switch is located near the door of the machine. Opening the door will stop the machine from operating. Some machines do not have this switch but have a locking solenoid. When the machine goes into the spin cycle, the solenoid latches the door to keep it from being opened during the spin cycle.

ELECTRICAL OPERATION.—Let's look at the electrical operation of a washer. With the plug connected to the outlet, the timer is turned to WASH and the dial is pushed in or pulled out, depending on the type of switch. The operational cycle continues as follows:

1. From the ON/OFF switch, power flows through the temperature control switch and the water-level switch to the inlet solenoid valve. That energizes the inlet valve, allowing the tub to fill.

2. The timer motor is de-energized during the fill cycle because of the open set of contacts in the water-level control switch.

3. Once the water reaches the proper level, one set of contacts opens to shut off the fill solenoid. The other contacts close, sending power to the timer and, at the same time, energizing the motor for the wash cycle.

4. At the end of the wash cycle, power is fed from the timer to the solenoid on the pump, engaging the pump and removing water from the tub.

5. Once the tub is empty, the solenoid for the spin cycle is energized. Its power is fed through the door switch to the solenoid so that, if the door is opened, the machine shuts down

6. During the spin cycle, the water pump is running, and the tub is operating at high speed The timer has provided a bypass circuit around the now open set of contacts in the water-level control switch

7. Once the cycle is completed, the pump, the high-speed solenoid, and the motor are de-energized because there is no water in the tub.

8. The water-level switch closes, energizing the inlet water solenoid to fill the tub for the rinse cycle.

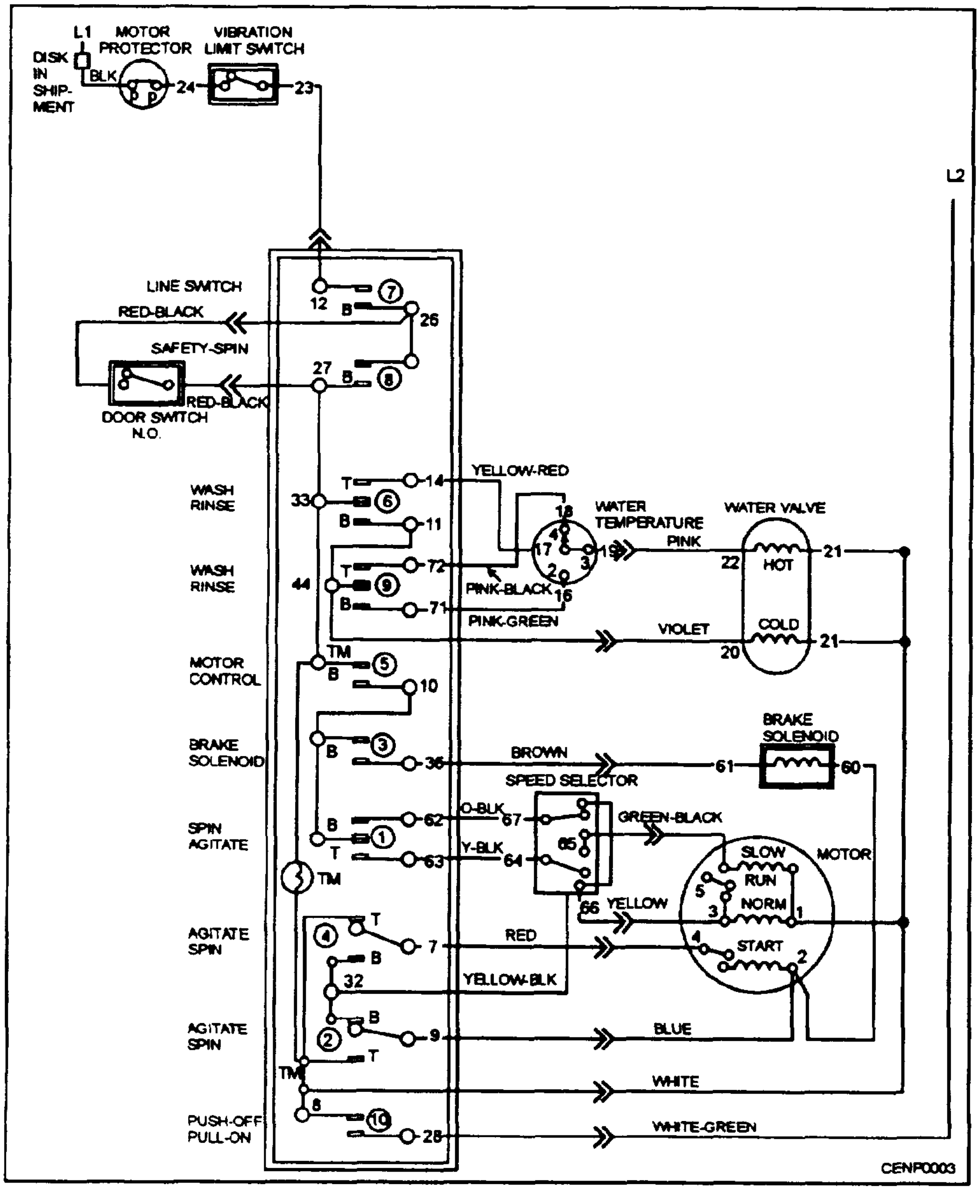


Figure 7-3.—Typical wiring diagram of a washing machine.

9. The rinse cycle is completed in the same manner as the wash cycle, and after this cycle, the timer shuts down, completing the operation.

TROUBLESHOOTING.—Before attempting any repair or replacement of any washing machine component, you must locate the trouble. Eliminate any guesswork. Guesswork can result in time-consuming repair. When troubleshooting a washer, you need to have the wiring diagram for that particular washer. Normally, it is pasted to the back panel. Try starting the machine and observing its operation. Run the machine through its cycles so you can trace the trouble to one circuit or component. Figure 7-3 shows a typical wiring diagram of a washing machine. The information shown in table 7-1 should help you troubleshoot a washing

Table 7-1.—Washing Machine Troublesbooting Chart

TROUBLE	PROBABLE CAUSE	REMEDY
Motor will not start. (No power at motor.)	Blown fuse. Broken wiring. Loose connections. Inoperative timer. Defective motor.	Replace fuse. Repair wiring. Tighten connections. Repair timer. Replace motor.
Motor will not turn. (Motor has power.)	Jammed water pump due to foreign matter. Transmission jammed. Low voltage.	Clean pump. Repair transmission. Correct voltage.
Motor runs but agitator does not.	Belt broken. Loose pulleys. Belt off pulleys. Faulty timer. Inoperative clutch. Broken gear in transmission. Loose connection at time or clutch solenoid.	Replace belt. Tighten pulleys. Replace belt on pulleys. Replace timer. Adjust clutch. Repair transmission. Tighten connection.
Washer washes but does not spin.	Water in tub. Faulty timer. Faulty clutch or transmission. Loose connection in spin circuit.	Check operation of water pump. Replace timer. Replace clutch or transmission. Tighten connection.
No water enters tub.	Clogged screen at water valve. Loose connection in water valve solenoid circuit. Defective solenoid. Water valve stuck. Defective timer.	Clean screen. Tighten connection. Replace solenoid. Repair valve. Replace timer.
Water does not drain.	Clogged drain valve screen. Defective water pump. Drain hose plugged. Defective timer. Pump belt broken.	Clean screen. Replace water pump. Unplug hose. Replace timer. Replace belt.
Noisy operation.	Loose pulleys. Cracked belt. Worn transmission. Worn pump. Loose cabinet parts.	Tighten pulleys. Replace belt. Replace transmission. Replace pump. Tighten parts.
Agitator operates when basket spins.	Improper electrical connection at timer. Defective clutch.	Correct condition. Repair clutch.
Washer stalls when running.	Frozen bearing. Transmission jammed. Off-balance load. Improper adjustment of vibration switch.	Replace bearing. Replace transmission. Distribute clothes evenly in tub. Adjust switch.
Washer leaks water.	Poor door or lid gasket. Pump seal defective. Hose connection loose. Machine overloaded. Too much water in tub.	Replace gasket. Replace seal. Tighten connection. Remove part of load. Check operation of water shutoff.
Washer does not cycle.	Faulty timer. Inoperative solenoids. Faulty wiring. Loose circuit connections. Crossed circuit wires. Broken transmission parts.	Replace timer. Replace solenoids. Repair wiring. Tighten connections. Check circuits with manufacturer's diagram. Replace transmission.

machine. It lists some of the troubles that can develop in a washer along with the probable causes and remedies for each.

Clothes Dryers

An electric clothes dryer is not as complicated as a washing machine; therefore, we will not go into as much detail on its operation as we did with the washing machine.

The main electrical parts of a dryer are as follows: electric-heating elements, thermostats to control heat, a motor to turn the drum assembly, and a timer to select cycle operations. Most dryers have a cutoff switch on the door that stops the dryer when the door is opened. Many dryers have a 40-watt ozone bulb to help condition the air. This bulb requires either a ballast coil or a ballast bulb. Both high-limit and low-limit operating thermostats are used in dryers to control the air temperatures that pass through the clothes. These are located in the exhaust housing and can be easily checked during operation by a voltage check. Your tester will indicate a voltage each time the contact is opened. Safety thermostats should show continuity between terminals at normal room temperature. Holding a small flame close to the thermostat should cause it to open, indicating an open circuit across its contacts.

Dryer timers are fairly simple to troubleshoot. Some timer drive motors and switching mechanisms can be replaced, but in most cases, it is more practical to replace the timer. Again, before attempting any repair or replacement of any parts, run the dryer through its cycles, eliminating any guesswork. Always refer to the wiring diagram for the particular dryer on which you are working. Figure 7-4 is a wiring diagram for a typical electric dryer.

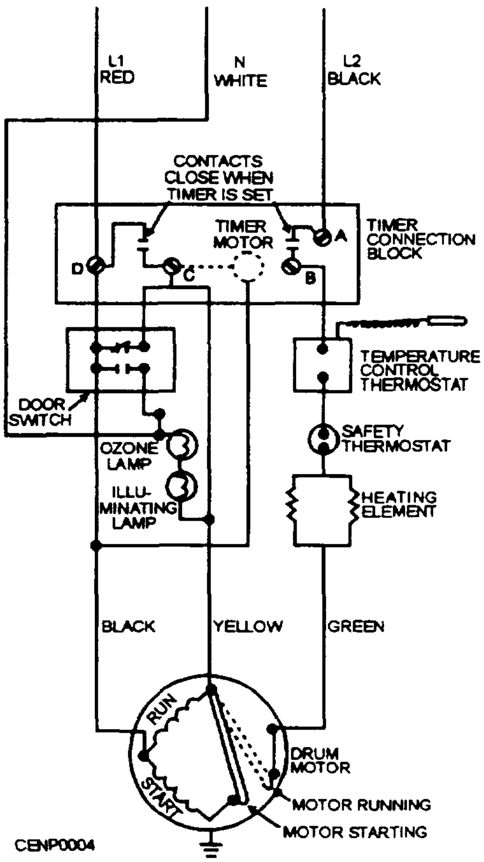


Figure 7-4.—Schematic of an automatic dryer.

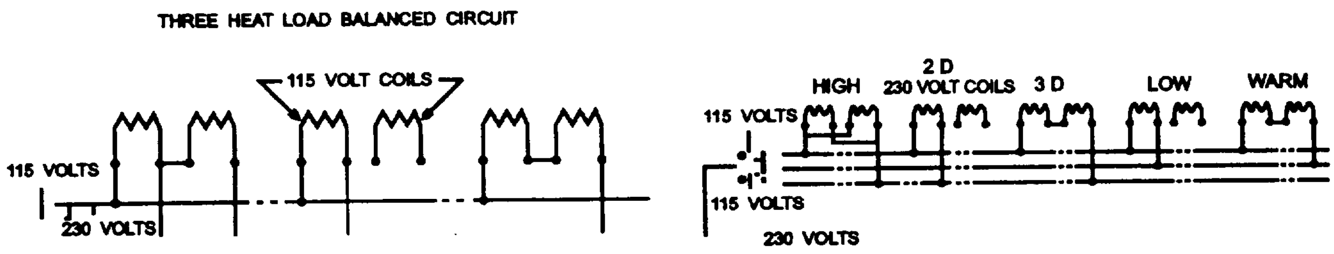
Electric Ranges

Electric ranges cook food by surface- and oven-heating elements. The surface elements, or burners, are on the top of the range, and the oven elements are within the oven. Electric ranges differ in size, but most standard ranges have four surface burners, a deep-well cooker, and an oven. Electric ranges vary in width from the 20-inch apartment size to the 40-inch full-size range. The approximate height of the surface burners from the floor is 35 inches.

The primary components of an electric range are the surface burners, deep-well cooker, oven, timer, and individual switches that control the temperatures of the heating units. The range usually has a convenience outlet to supply electricity for a coffee percolator, waffle iron, or toaster, which you can operate on the top of the range. The range is usually automatic. The oven control keeps the temperature of the oven at a set point, and an electric clock and timer shut off the oven at a predetermined time. The individual switches that control the temperatures of the surface burners are usually located on the front of the range.

The principle of operation of an electric range is simply that of an electric current passing through a resistance, thereby producing heat. The resistance is usually nichrome wire.

Heating elements used in ranges may be of the open or the enclosed types. The surface burners usually have enclosed tubular or cast-in elements. Each element is controlled by an individual switch that can control the element for as many as 10 different heat positions. The electrical power supply to each element is either 120 volts or 240 volts or both, depending upon the heat position of the switch Each surface burner is connected to a signal light that indicates when the unit is in the ON position. In the wiring schematic shown in figure 7-5, you can see the wiring of a typical electric range.



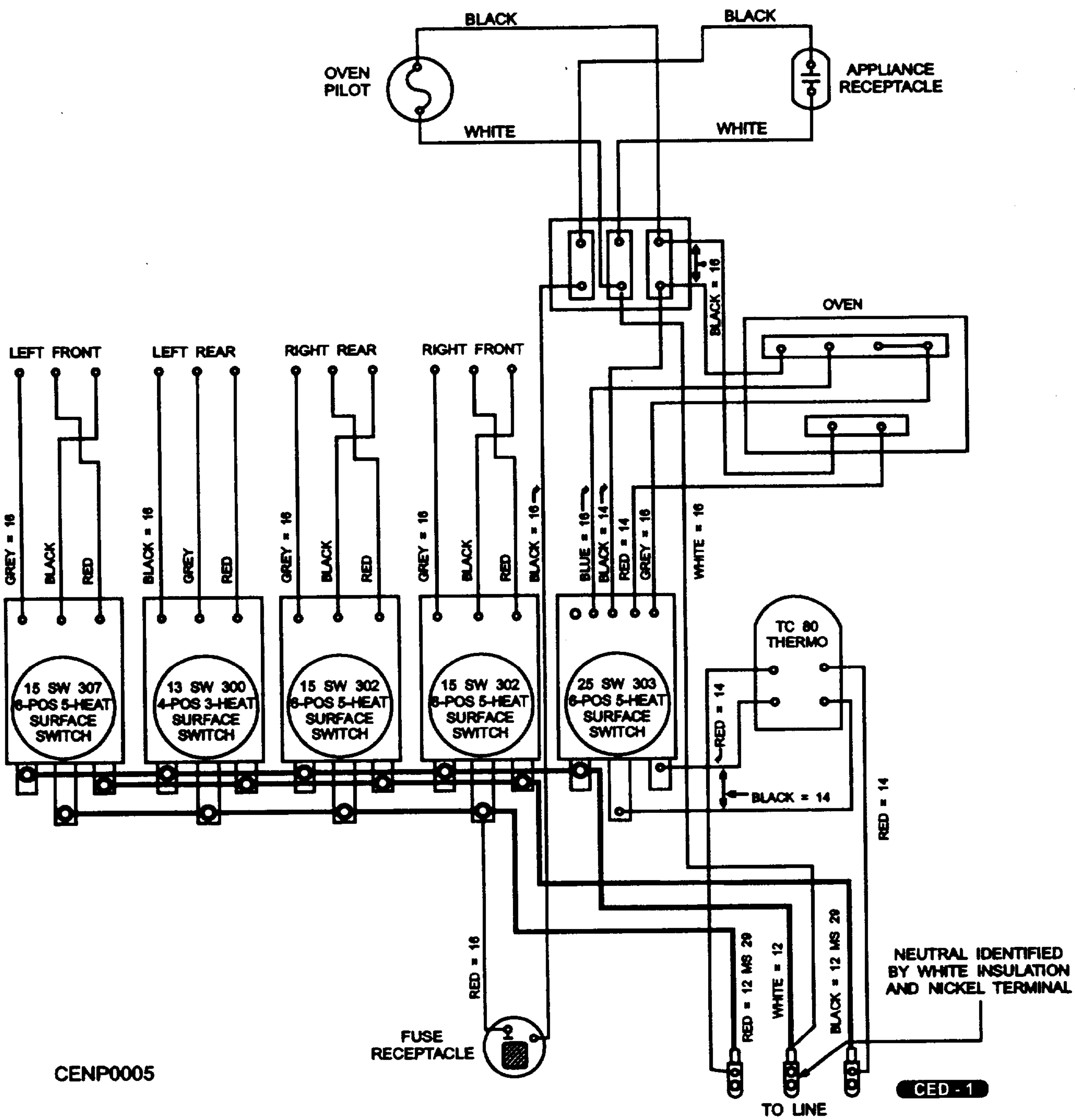


Figure 7-5.—Typical electric range wiring schematic.

OVEN-HEATING ELEMENTS.—The ovens of electric ranges are equipped with open or enclosed elements. These include the rod and coil, suspended coil, spiral-wound, or tubular types. Ovens have two heating elements. One is located in the upper part of the oven and the other in the lower part. Oven elements work off a thermostat to control heat temperature and a timing device for automatic shutoff, as shown in figure 7-6.

TROUBLESHOOTING.—In troubleshooting, start by checking to ensure that proper voltage is going to the unit; then check each element and control device. The heating element, though ruggedly constructed, might become open-circuited. That can be checked with an ohmmeter. Normal resistance is somewhat less than 100 ohms. If elements are opened, replacement is necessary.

If the heating element checks normal but the unit does not heat up, the controls should be checked. Voltage measurement is the most reliable test for a switch. When turned off, the measurement across the switch terminals should read "FULL-LINE VOLTAGE," 120 or 240 volts. When the switch is ON, the reading should be zero across the terminals. Any voltage reading across the terminal of a closed switch indicates a fault. Replacing a faulty switch involves the disconnection and replacement of many wires. A sketch or identifying tags should be used to ensure the correct relocation of the wires.

Oven thermostats control temperature and are factory-calibrated for that unit. Some units can be recalibrated but most must be replaced. When replacement is necessary, the exact type is preferred; however, universal type replacement is available. The manufacturer's instructions that come with a thermostat will give you the exact method for installing and calibrating the device.

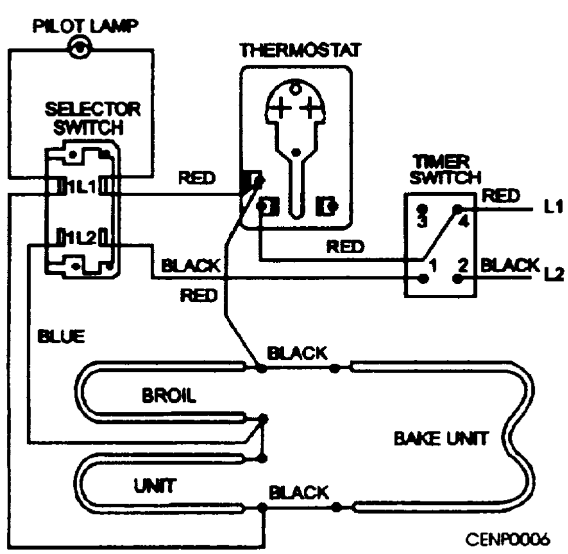


Figure 7-6.—Oven-heating circuit with two heating units.

Faulty wiring is the final check. Unless arcing damage is evident, test a wire by disconnecting both ends from the circuit; then check it with an ohmmeter. A good wire checks 0 ohms; a faulty one, infinity (∞). Table 7-2 is a guide that should help you when troubleshooting electric ranges; it lists the trouble, probable cause, and remedy.

Hot-Water Heaters

A hot-water heater is nothing more than a metal water-storage tank with one or two electric heating elements, thermostatically controlled to heat water in the tank. Some of the electrical problems you may encounter are as follows: no power, defective thermostat, thermostat out of calibration, or a defective heater element or elements.

The hookup for a hot-water heater will vary depending on the size and application of each unit. Always refer to the manufacturer's manual for wiring instructions and the NEC© for any special requirements. Most hot-water heaters that you will be installing will have a wiring diagram similar to the one shown in figure 7-7. The thermostat is in series with the

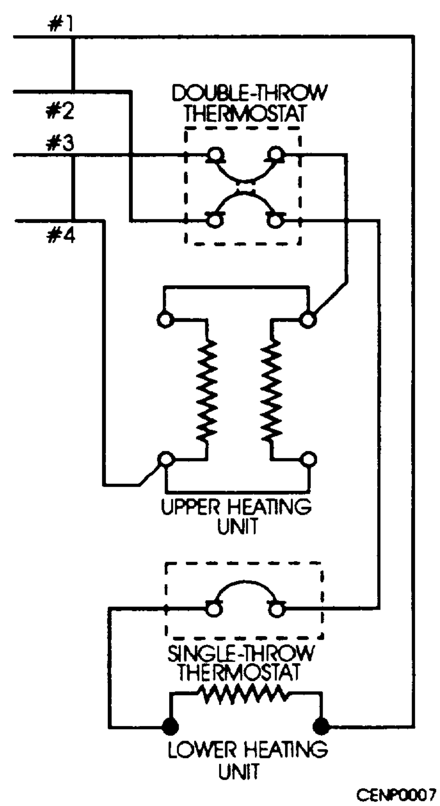


Figure 7-7.—Wiring connections for an electric water beater, having two heating units

Table 7-2.—Troubleshooting Guide for Electric Ranges

TROUBLE	PROBABLE CAUSE	REMEDY
Range will not heat.	No voltage at outlet.	Correct voltage.
	Blown fuse.	Replace fuse.
	Open breaker.	Reset breaker.
	Broken wire in power cord.	Check continuity of cord.
	Faulty wall outlet.	Check for voltage at outlet.
	Faulty prongs on male plug.	Replace if necessary.
	Faulty slots in wall outlet.	Replace if necessary.
No heat at one surface burner.	Loose terminal connections at burner unit.	Clean and tighten connections.
	Corroded contacts in control switch.	Clean contacts with sandpaper.
	A burned-out element.	Replace element.
	Open in burner circuit.	Replace wires if necessary.
Surface burner too hot.	Incorrect or reverse connections.	Switch wires as required.
No heat in oven.	Element connections loose and corroded.	Clean and tighten connections.
	Burned-out element or elements.	Replace elements.
	Inoperative oven control.	Adjust or replace control.
Oven too cool.	Inoperative oven control.	Adjust and replace control.
	Improper voltage at element.	Check and increase voltage.
	Open in one section of element.	Check and replace element if necessary.
	Loose and corroded element connections.	Clean and tighten connections.
Oven too hot.	Inoperative oven control.	Adjust or replace control.
	Wrong element.	Install proper element.
Uneven baking.	Range tilted.	Level range.
	Oven racks not on proper supports.	Place racks on proper supports.
Appliances fail to heat when plugged into appliance outlets.	Blown fuse.	Replace fuse.
	Loose and corroded circuit connections.	Clean and tighten connections.
	Broken circuit wires.	Replace wires.
	Faulty outlet.	Replace if necessary.

heating element and has only one set of contacts that open and close in response to the temperature at the bottom of the water-heater tank. The double-throw thermostat controls both the upper and lower heating elements. The switch closes the circuit in the upper heating unit whenever the water temperature in the top of the tank becomes lower than the thermostatic switch setting. When the top part of the tank reaches a preset temperature, the switch opens the contacts to the upper unit and, by toggle action, closes the contacts to the lower unit. The lower unit comes on and remains on until its preset temperature is reached and the thermostat is satisfied.

APPLIANCE CONTROLS

Appliance controls, as the name implies, regulate the use of electrical appliances used everyday. They allow us to turn appliances on and off. There are two general classes of controls: manual and automatic.

MANUAL CONTROLS

Manual controls turn the appliance on and off, and some types set the appliance at a desired temperature by controlling the current flow to the unit. The automatic control, in addition to turning the unit on and off, maintains an even heat in the unit; for example, the automatic controls on kitchen appliances result in better

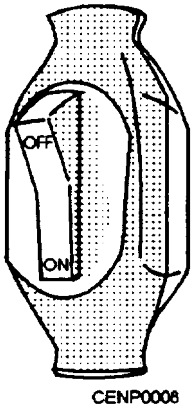


Figure 7-8.—In-line toggle switch.

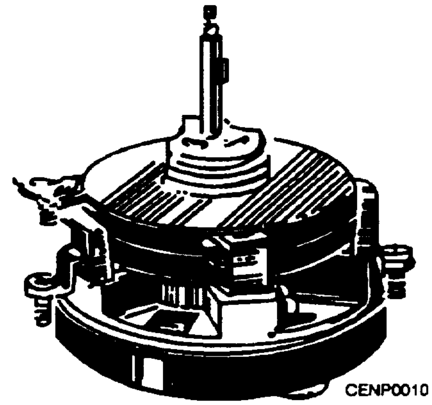


Figure 7-10.—Typical rotary switch.

food preparation and allow more time for the food preparer to accomplish other tasks.

Manual controls turn the heating unit on and off by making or breaking the electrical circuit. Manual controls consist of the toggle switch and different types of rotary switches.

Toggle Switches

Toggle switches are used to make and break the electrical circuit on many small appliances. Figure 7-8 shows one type of toggle switch that is installed in an appliance cord. This type of switch cannot be repaired. You must replace it. Figure 7-9 shows a typical wall-mounted toggle switch used to control appliances. New switches are usually so inexpensive that repairing an old one is not economical.

Rotary Switches

Rotary switches have fast make-and-break action and usually have three or more heat settings. The spring action contained in this type of switch enables it to operate extremely fast and eliminates the usual pitting and burning of its contacts.

Rotary switches are normally used to control the top elements of an electric range. Changing the position of the switch changes the connection to the element and varies the voltage; for example, the LOW position connects the elements in series to a 120-volt Rower source, and the HIGH position connects the elements in parallel to a 240-volt power source. Various combinations of these connections deliver different heat from the unit, all controlled by the rotary switch. Figure 7-10 shows a typical rotary switch.

Repair of this switch is recommended only as a temporary measure. Repair consists of cleaning and adjusting contacts, replacing worn and inoperative parts, and lubricating the contacts and switch mechanism with nonoxide grease for smoother operation. The switch should be replaced as soon as a replacement is available.

The pull-to-turn switch, as shown in figure 7-11, is constructed to carry the higher loads connected with

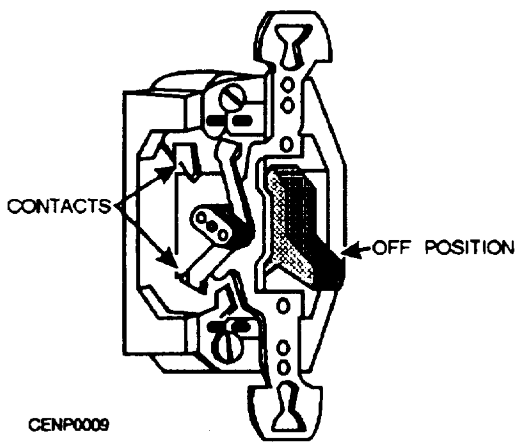


Figure 7-9.—Typical wall-mounted toggle switch.

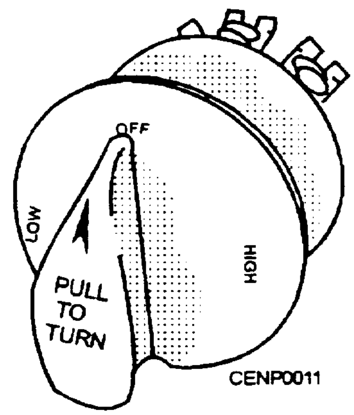


Figure 7-11.—Pull-to-turn switch.

commercial ranges and oven installations in galleys. The current is interrupted ahead of the make-and-break action of the switch contacts. That eliminates the usual pitting and burning of contacts. This switch cannot be repaired; you must replace it.

AUTOMATIC CONTROLS

The basic function of an automatic control is turning current on and off as required to maintain a desired temperature.

Bimetallic Blade Control Switch

The bimetallic blade control switch, as shown in figure 7-12, is operated by the expanding and contracting effect caused by heating two pieces of dissimilar metals that are welded together. Repair of this control is limited to an adjustment in its temperature setting.

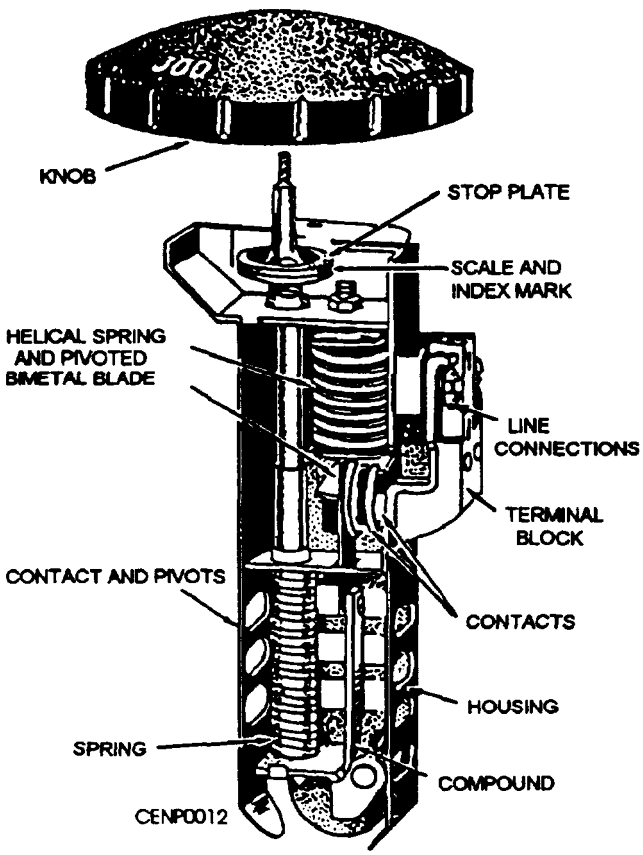


Figure 7-12.—Bimetallic blade control switch.

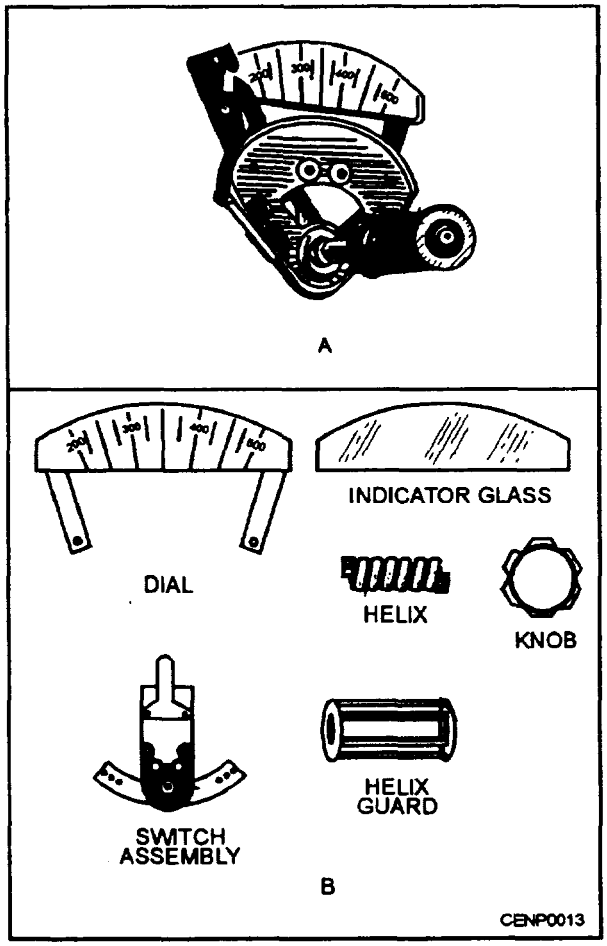


Figure 7-13.—A. Helix control; B. Helix components.

Helix Control

A helix control (fig. 7-13, view A) is used in some domestic, semi-commercial, and commercial installations. It is operated by thermostatic metal that coils and uncoils when heat is applied, regulating a switch to make and break the electric circuit. Repairing this unit consists of replacing miscellaneous parts, such as the dials, switch assembly, helix, helix guard, and so on (fig. 7-13, view B).

Hydraulic Control

A hydraulic control is probably the most frequently used control for automatically regulating the temperature of cooking appliances. In this control, a capillary tube filled with fluid is connected to hydraulic bellows (fig. 7-14). A bulb located on one end of the capillary tube is filled with fluid and then is put in the heat zone. It transfers heat-created pressure through the capillary to the diaphragm. The expanding diaphragm presses a system of levers that snap the electrical contacts open, thus cutting off electrical current to the controls. Automatic recycling takes place with slight temperature drops, maintaining a constant set temperature.

Certain types of hydraulic controls have a safety device, normally set at 450°F, that trips upon reaching the set temperature and requires manual resetting. It may take several hours before the appliance has cooled down enough to allow the operator to reset the unit.

Repairing a hydraulic control is usually limited to adjusting the temperature setting to correspond with the temperature recorded in the appliance. You can adjust the temperature control by loosening, but not removing, the two small, slotted lock screws (fig. 7-14) that are behind the dial. Now, with one hand, hold the main center hub of the control and move the slotted adjusting plate to the right to raise the temperature or to the left to lower the temperature. That is a delicate adjustment, so move the dial a little at a time.

If you find that the circular slots in the adjusting plate prevent you from turning the plate for the desired temperature change, remove the two lock screws carefully so you can move the adjusting plate a full 180 degrees. Replace the two adjusting screws and continue the calibration process as before.

A timer is used to control a circuit to an appliance automatically or give a warning to the operator that a predetermined time has lapsed. Figure 7-15 shows a typical wiring diagram of an electric range single-pole oven timer.

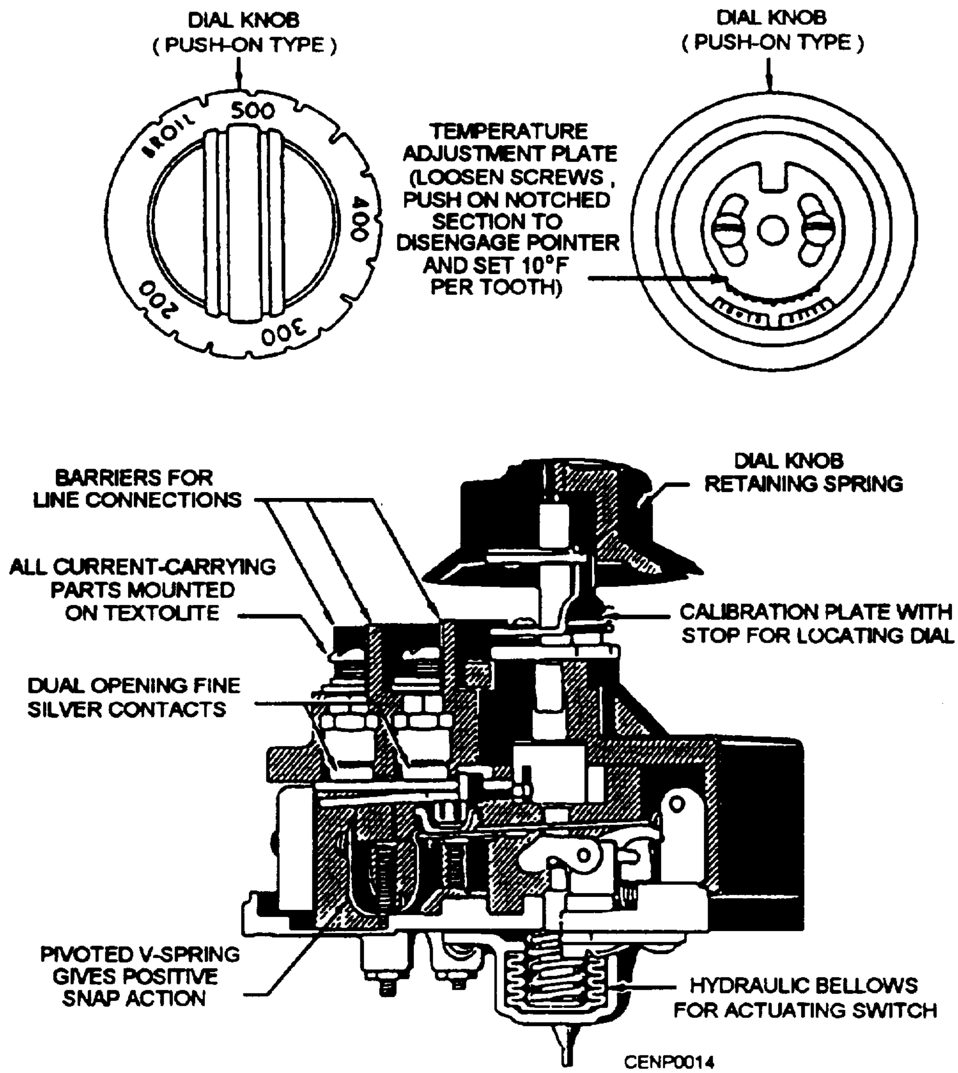


Figure 7-14.—Hydraulic control.

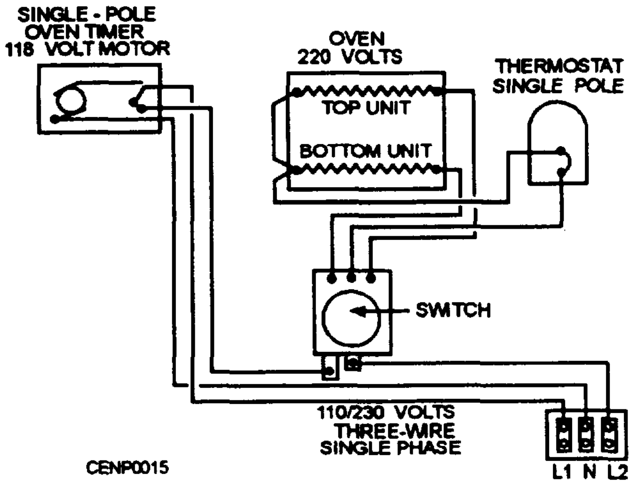


Figure 7-15.—Single-pole oven timer wiring schematic.

APPLIANCE AND EQUIPMENT MAINTENANCE, REPAIRS, AND TROUBLESHOOTING

Identifying and locating problems within circuits, appliances, and equipment is a challenging job. This phase of your rating as a Construction Electrician (CE) working within a maintenance shop is where much of your career will be spent.

INSPECTION

To locate faulty conditions in circuits, you need to perform some inspecting, some calculating, and some instrument testing. A few moments spent studying the schematic or drawing of a particular circuit before the actual troubleshooting begins often simplifies the task of isolating the trouble. THINK! If a circuit fails to operate properly, apply some logical reasoning when you check for the fault. The trial-and-error method is inefficient and time-consuming.

When you troubleshoot a circuit, the first thing you want to do is study the schematic; the next step is to inspect the circuit visually. Check for loose connections, loose wires, burnt wires, and burnt components, and check the type of wiring.

Careful inspection of electrical components and equipment is essential to preventing fire hazards caused by defects or dangerous conditions. These inspections include checking for cleanliness, normal operation, operation under load, tight connections, adjustment, and lubrication Always perform a visual inspection first. In this inspection, examine the general condition of the equipment, determine whether it was abused, dropped, or overloaded or is inoperative because of continued use. The general condition of a unit can help you to determine the fault within it.

Testing and maintaining equipment is best accomplished at the time of inspection. Completing everything without returning to the area saves time. Tools and test equipment should be taken to the job site when the inspection is performed.

PREVENTIVE MAINTENANCE

One of the primary responsibilities of a CE is to ensure proper operation of switches and elements used in appliances and equipment. That can be done by developing and following a good inspection and maintenance program. Periodically, you should check all equipment for loose connections, burned or pitted contacts, and the improper mounting of switches. You should also check for bad connections, improper mounting, and loose or broken insulators on coils or ribbon elements.

The inspection and maintenance of switches and elements on appliances and equipment go hand in hand, and, in most cases, a problem discovered during inspection is corrected on the spot and requires no further work until the next inspection.

TROUBLESHOOTING

A bad appliance should first be checked visually. If you fail to find the trouble by visual inspection, you will find that a meter is an indispensable device in testing electrical circuits of appliances.

Power Supply and Cord

When you attempt to repair an inoperative appliance, do not be in a hurry to disassemble it to find the trouble. You should first pull the power cord from the outlet and determine if there is current at the outlet. If the outlet is energized, inspect the power cord. Next, examine the plug connections for cleanliness and tightness. Finally, inspect the power cord for any broken wires. If the condition of the cord makes it unserviceable, replace it before going any further in your troubleshooting procedure.

Checking the power supply and the condition of the power cord should be the first thing you do when you attempt to find an electrical fault in an appliance. In a number of cases, electrical faults are found in the power cord, rather than in the appliance itself. Only when you have determined that the fault is not with the power supply or cord, should you consider troubleshooting the internal units. To troubleshoot these units effectively, you have to disassemble part of the appliance.

WARNING

When you are troubleshooting and doing repair work, TREAT ELECTRICITY WITH RESPECT. Working with electricity is hazardous, and you must take every precaution to avoid electrical shocks, burns, and electrocution. Regard all circuits as live until you have opened the switches or have made voltage tests and know that the circuit is dead. Lock and tag all switches in the OPEN position to keep other personnel from tampering with them and creating a safety hazardous condition. Remove protective devices, such as fuses, from their holders. REMEMBER, YOU WILL BE WORKING ON THAT CIRCUIT.

Controls and Elements

Controls and elements on appliances or equipment will most likely be your biggest problem. Check switches and controls with an ohmmeter for the making or breaking of contacts. If the switch is ON, the ohmmeter should read "0." The operation of a switch can be checked with a voltmeter. Check for voltage input and output.

New switches are usually inexpensive, so repairing an old one is not economical. The contacts may be reformed as a temporary measure to ensure a positive contact for completing the circuit. Lubricating the contacts and spring mechanics with a nonoxide grease reactivates the switch operation.

Repair of the bimetallic blade control switch is limited to an adjustment in the temperature setting of the control to agree with the temperature recorded in the appliance or equipment being tested. Temperature of equipment should be tested by a reliable temperature tester or a good thermometer.

Repair of the helix control is limited to adjusting the temperature setting of the control to agree with the temperature recorded in the appliance or equipment being tested. If the control cannot be adjusted, the complete control assembly must be replaced.

If a timer fails to operate, use the following procedures to locate the trouble:

- Test the electrical circuit for a blown fuse.
- Check for friction between the hands of the timer and timer crystal.
- Check all wire connections.

To repair an inoperative electric timer, perform the following steps:

- Replace the blown fuse with a fuse of the proper rating.
- Replace the complete rotor if the rotor is inoperative.
- Replace the complete coil assembly if the field coil is burned out.
- Repair the timer switch assembly by cleaning contacts or reforming the contact arm to ensure positive contact. If the contact shows excessive wear, replace the switch assembly.
- Adjust the hands of the timer if they are binding.
- Check all connections at the back of the timer for positive contact to ensure a complete circuit.

Elements can be checked using a -voltmeter or ohmmeter. If a voltmeter is being used remove one wire from the element and check for voltage between the empty terminal and ground. A voltage reading indicates a good element, and no voltage indicates an open or defective element.

If an ohmmeter is used, first ensure that the power is disconnected. Remove both conductors to prevent a false reading. Connect the two leads of the ohmmeter to the two terminals of the element. A reading of zero indicates a good element. A reading of infinity symbol indicates an open element.

PORTABLE ELECTRIC TOOL TESTERS

If you have ever had an encounter with an ungrounded electric drill while working in the rain, you have a feel for the importance of tool testing. You will also have gained a healthy respect for the person who tests tools at the battalion central tool room (CTR) or the Public Works Department (PWD) when he or she fmds and corrects the problem with portable electric power tools.

The tool tester shown in figure 7-16 is an example of a tool tester that personnel from CTR or PWD might use.

The tool tester consists of a transformer, sensing relays, indicator lights, an audible warning buzzer, and leads suitable for tool or appliance connections.

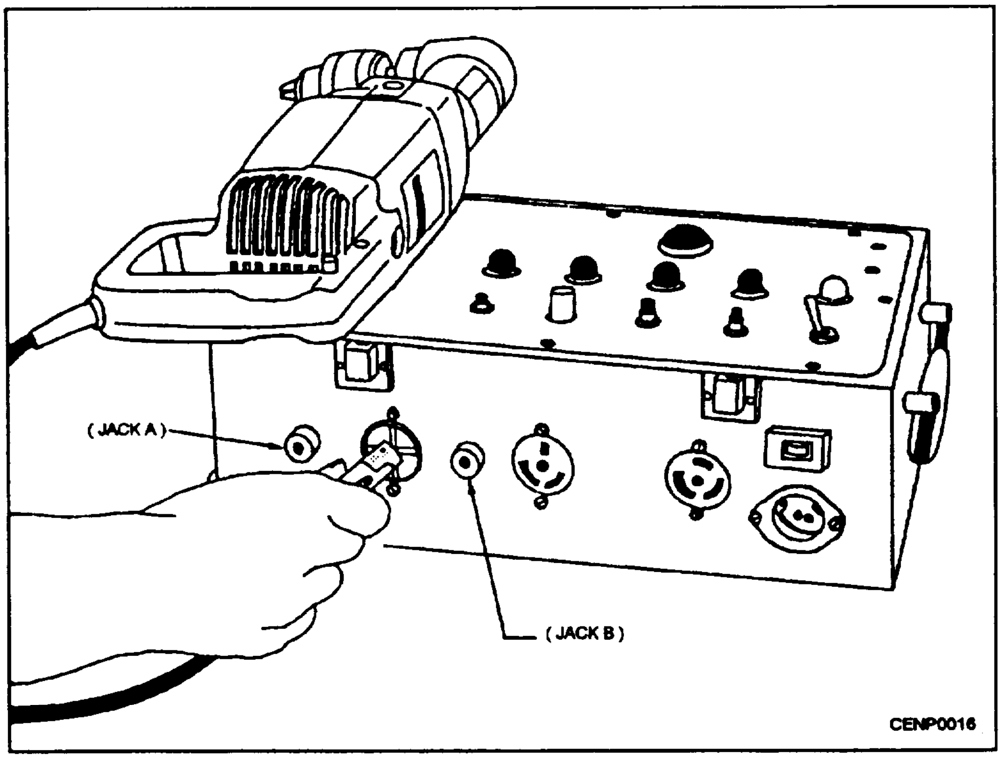


Figure 7-16.—Typical tool tester.

The transformer passes approximately 30 amperes through the tool cord equipment ground, burning away any “whiskers” that may be causing a poor equipment ground If there is no equipment ground, the OPEN EQUIPMENT GROUND sensing relay is activated, and appropriate warnings are given (the OPEN EQUIPMENT GROUND light glows).

If the resistance of the ground on the equipment under test is approximately 0.2 to 1.5 ohms, the FAULTY EQUIPMENT GROUND sensing relay is activated Resistance in excess of this amount activates the OPEN EQUIPMENT GROUND sensing relay.

The range in length of extension cords that can be tested is from approximately 6 feet to 100 feet of 16-gauge wire. These lengths will be longer or shorter in other gauges. The sensing circuit can be adjusted for different sensitivities.

The presence of a dangerous POWER GROUND, caused by carbon, moisture paths, or insulation breakdown, is checked at a 500-volt potential or at a 120-volt potential when the RF TEST button is pressed. The equipment, line cord, and switch are tested for SHORT CIRCUIT.

Faulty conditions are indicated by the corresponding light (red) and buzzer. One faulty condition must be corrected before another one will be indicated.

Tests proceed only when the equipment ground is in a safe condition. All tests (except the power ground) are conducted at potentials less than 10 volts.

If no electrical defects are found, the tool operates at its proper voltage to reveal any mechanical faults.

Optional features are installed to simplify two-wire and double-insulated tool tests and provide for safely testing double-insulated tools for power grounds.

WARNING

The tool operates at the end of the test cycle. Be sure moving parts are faced away from the operator and have proper clearance to operate. Remove any removable cutting blade or bit before the tool is tested Do not come in physical contact with the tool during the test.

MAINTENANCE OF POWER TOOLS

It is the task of a CE to ensure the proper operation of all power tools within his or her realm of responsibility. The program itself will be formulated by higher authority. The best way to perform this task is to develop a good inspection and maintenance program. Periodically, you should check all power tools for loose connections, pitted contacts, improper mounting of switches, and so forth.

The inspection and maintenance of power tools go hand in hand, and, in most cases, a problem discovered during inspection is corrected on the spot and requires no further work until the next inspection.

TEST EQUIPMENT

Test equipment and experienced Construction Electricians are not always needed to locate problems. Anyone who sees a ground wire dangling beneath a lightning arrester might suspect a problem. Little skill is required to consider an electrical service problem as a possible reason for the lack of power in a building.

Arcing, loud noises, and charred or burned electrical equipment sometimes indicate electrical faults; however, hidden, noiseless circuit problems are much more common and usually much harder to locate.

The right test equipment and the Construction Electrician who knows how to use it are a valuable combination for solving electrical circuit problems.

No attempt will be made in this chapter to explain the internal workings of test equipment, such as meter movement or circuitry. Information on these subjects is covered in Navy Electricity and Electronics Training Series (NEETS) modules, published by the Naval Education and Training Program Management Support Activity. Test equipment is discussed in Modules 3 and 16. Your education services officer (ESO) should stock the NEETS modules. If not, he or she can order them for you. Other information on the use of test and circuit measuring equipment is included in modules throughout the NEETS series. This section introduces to you the types of test equipment used by the Construction Electrician in the field.

WARNING

Naval Facilities Command (NAVFAC) requires that tests of electrical equipment be performed under the supervision of qualified electrical personnel. If in-house personnel are not available for these tests, the services of a qualified electrical testing contractor may be used. If you do not know how to do certain tests that must be performed, go to your seniors (crew leader and/or project chief). Be certain that you can perform the test safely before starting the test procedure.

AMMETERS

A meter used to measure the flow of electric current is a current meter. Current meters that measure current in amperes are called ammeters. The ammeter is connected in series with the circuit source and load. Panel-mounted ammeters, such as those used in power plants, are permanently wired into the circuit. Figure 7-17 shows two typical panel-mounted ammeters.

Portable ammeters are temporarily connected into a wiring system at whatever point in the system a current reading is desired; for example, feeder current is measured by opening the feeder and wiring the meter in series with the feeder source and load. Circuits branching off the feeder may be opened and an ammeter inserted into the branch.

Using a clamp-on ammeter (fig. 7-18) is an exception to the rule previously stated requiring ammeters to be series-connected. The clamp-on ammeter consists in part of clamp-on transformer jaws that can be opened and placed around a conductor. The

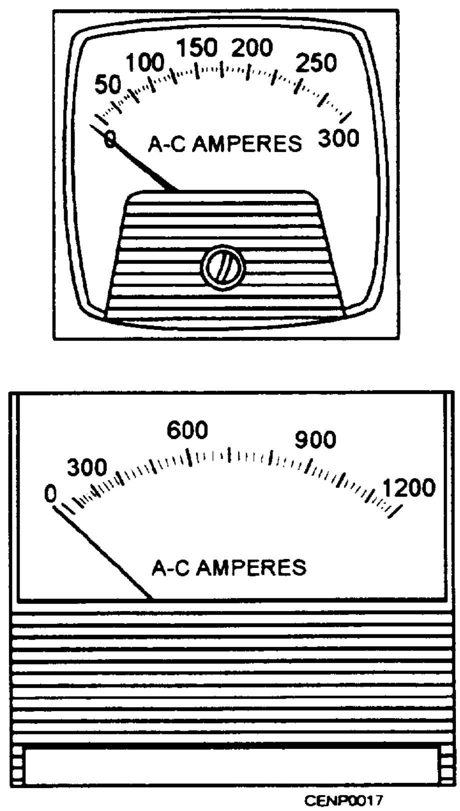


Figure 7-17.—Typical panel ammeters.

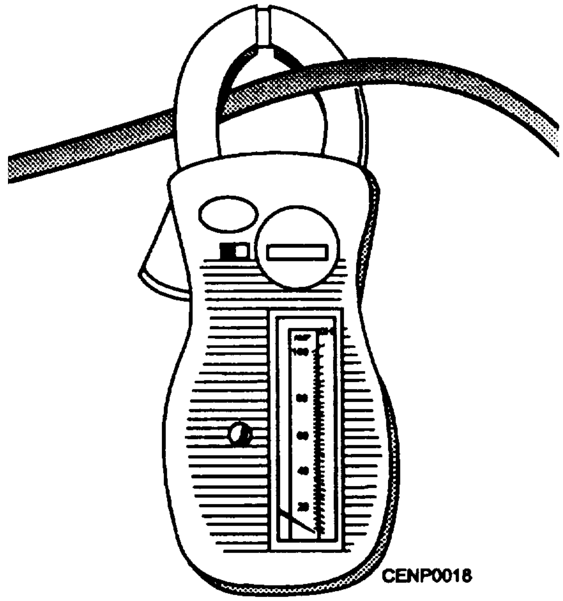


Figure 7-18.—Clamp-on ammeter.

jaws are actually part of a laminated iron core. Around this core, inside the instrument enclosure, is a coil winding that connects to the meter circuit. The complete core (including the jaws) and the coil winding are the core and secondary of a transformer. The conductor, carrying the current to be measured, is like a primary winding of a transformer. The transformer secondary is the source of power that drives the meter movement. The strength of the magnetic field surrounding the conductor determines the amount of secondary current. The amount of secondary current determines the indication of current being measured by the meter.

All ammeters will have an adjustable scale. The function and range of the meter are changed as the scale is changed.

To take a current measurement, turn the selector until the AMP scale you wish to use appears in the window. To take measurements of unknown amounts of current, you should rotate the scale to the highest amperage range. After taking the reading at the highest range, you may see that the amount of current is within the limits of a lower range. If so, change the scale to that lower range for a more accurate reading.

After choosing the scale you want, depress the handle to open the transformer jaws. Clamp the jaws around only one conductor. The split core must be free of any debris because it must close completely for an accurate reading.

To measure very low currents in a small flexible conductor, you may wrap the conductor one or more times around the clamp-on jaws of the meter. One loop will double the reading. Several loops will increase the reading even more. After taking the measurement, divide the reading by the appropriate number of loops to determine what the actual current value is.

The clamp-on ammeter is convenient and easy to use. To measure the current of a single-phase motor, for example, simply rotate the selector until the desired amp scale appears, clamp the jaws around one of the two motor conductors, and take the reading.

Some clamp-on instruments are capable of more than one function; for example, they are designed for use as an ohmmeter or a voltmeter when used with the appropriate adapter or test leads.

VOLTMETERS

The meter component (or voltage indicator) of a voltmeter is actually a milliammeter or a micrometer. This instrument is series-connected to a resistor (called a voltage multiplier) to operate as a voltmeter. The series resistance must be appropriate for the range of voltage to be measured. The scale of an instrument designed for use as a voltmeter is calibrated (marked off) for voltage measurements.

Panel voltmeters are similar in appearance to the ammeters shown in figure 7-17, except for the calibration of the scale. Examples of typical panel voltmeters are shown in figure 7-19. Voltmeters are

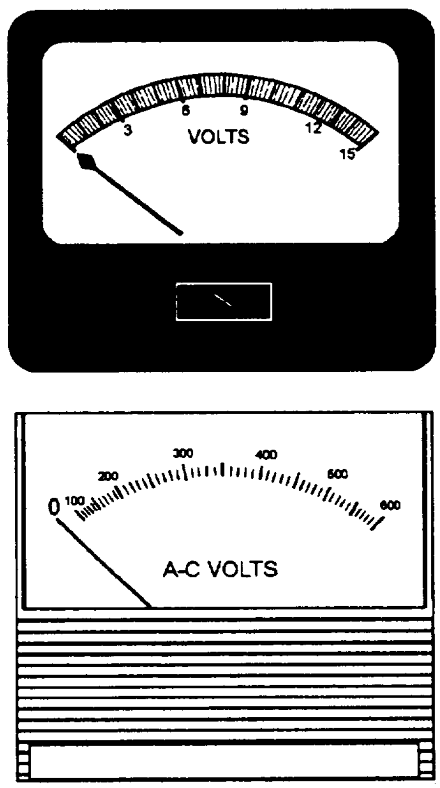


Figure 7-19.—Typical panel voltmeters.

connected across a circuit or voltage source to measure voltage. Panel-mounted voltmeters are permanently wired into the circuit in which they are to be used.

Portable voltmeters are designed to measure one or more ranges of voltage. Those intended for measurement of more than one voltage range are provided with range selector switches. The range selector switch internally connects the appropriate multiplier resistor into the meter circuit for the range of voltage to be measured; for example, a voltmeter may be designed to use a O-l milliampere milliammeter as a voltage indicator. For each setting of the selector switch, a different multiplier resistor is connected into the meter circuit. For each selection, a particular resistor value is designed to limit the current through the milliammeter to a maximum of 1/1,000 of an ampere (1 milliampere) for a full-scale reading.

In a similar way, voltmeters designed to use a micrometer, for example, a 50-microampere meter, include multiplier resistors that limit the meter current to a maximum value of 50 microamperes. In this case, 50 microamperes are flowing through the meter for a full-scale deflection of the needle.

Voltmeters that use either a milliammeter or micrometer to indicate voltage have a scale calibrated to read directly in volts. The flow of current in either type of meter represents the electrical pressure (voltage) between two points in an electrical circuit; for example, the two points may be the hot (ungrounded) conductor and the neutral (grounded) conductor of a 125-volt circuit. In this case, the voltmeter is said to be connected across the line.

LINE VOLTAGE INDICATORS

The line voltage indicator (fig. 7-20) is much more durable than most voltmeters for rough construction work. Its durability is mainly due to its simple design and construction. It has no delicate meter movement inside the case as do the analog meters previously mentioned. The two test leads are permanently connected to a solenoid coil inside the molded case.

CAUTION

Do not use the line voltage indicator on voltages exceeding the capabilities of the indicator.

An indicator, attached to the solenoid core, moves along a marked scale when the leads are connected across a voltage source. The movement of the core is

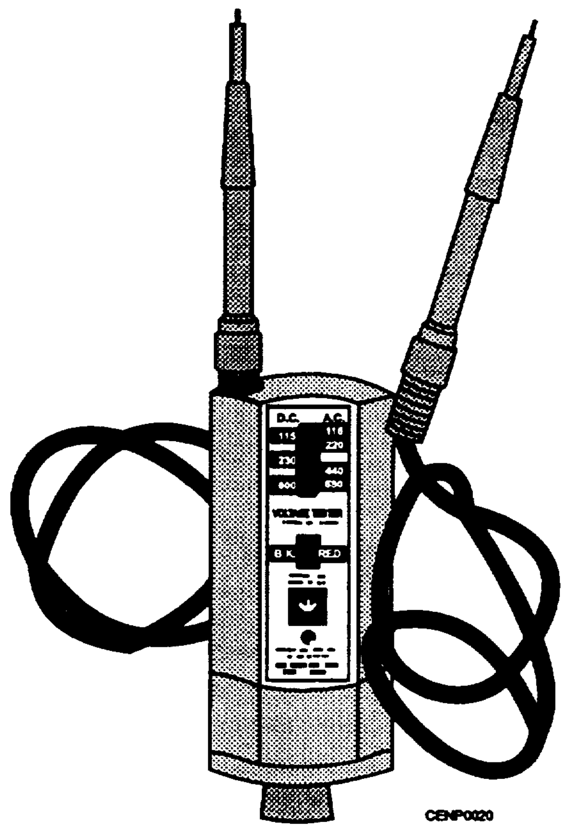


Figure 7-20.—Line voltage indicator.

resisted by a spring. The indicator comes to rest at a point along the scale that is determined by both the strength of the magnetic field around the solenoid and the pressure of the opposing spring. The strength of the magnetic field is in proportion to the amount of voltage being measured.

In the center of the tester is a neon lamp indicator. The lamp is used to indicate whether the circuit being tested is ac or dc.

When the tester is operated on ac, it produces light during a portion of each half-cycle, and both lamp electrodes are alternately surrounded with a glow. The eye cannot follow the rapidly changing alternations so that both electrodes appear to be continually glowing from ac current. Two other indications of ac voltage are an audible hum and a noticeable vibration that can be felt when the instrument is hand-held.

When the tester is operated on dc, light is produced continuously, but only the negative electrode glows; therefore, the tester will indicate polarity on dc circuits. Both the test probes and the glow lamp enclosure are colored red and black. If, while you are testing a dc circuit, the electrode of the glow lamp on the side colored black is glowing, this glow indicates the black probe of the tester is on the negative side of the circuit; likewise, the opposite electrode glows when the red probe of the tester is on the negative side of the circuit.

The neon lamp is not the only method used on line voltage indicators to indicate dc polarity; for example, the Wigginton voltage tester, manufactured by the Square D Company, uses a permanent magnet mounted on a rotating shaft The ends of the magnet are colored red and black. The magnet is viewed from a transparent cap located on top of the tester. When the red portion of the magnet is up, the red test prod is positive. When the black portion of the magnet is up, the black prod is positive. Neither type of line voltage indicator vibrates when measuring dc.

Be certain to read and understand the instructions for the particular instrument you use. As you can see from this example about polarity indicators, because of variations in similar instruments, you could easily misunderstand an indication from one instrument when thinking of the instructions for another.

The line voltage indicator is not used to determine the exact amount of circuit voltage. That presents no problem for most of the work done by Construction Electricians. As you become proficient in the use of the solenoid type of voltage indicator, you can tell approximately what the voltage is by the location of the indicator within a voltage range on the scale.

OHMMETERS

The resistance of a component or circuit, in ohms, can be determined by using Ohm's law. With the instruments we just discussed, you can find circuit current and voltage. From electrical theory you already know that voltage divided by amperage equals resistance. But the fastest method of determining resistance is by taking a resistance reading directly from an ohmmeter.

The simplest type of ohmmeter consists of a housing that includes a milliammeter, a battery, and a resistor connected in series, as shown in figure 7-21. The ohmmeter is designed so that the resistor R_1 limits the current though the milliammeter to a value that results in a full-scale deflection of the meter needle. The scale (fig. 7-22) is calibrated in ohms. By using several resistors, more than one battery, and a selector switch (to select one of the several resistors and batteries), you can make the ohmmeter include more than one resistance range.

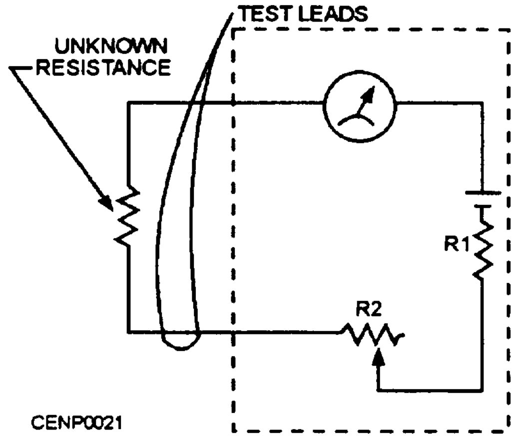


Figure 7-21.—A simple series ohmmeter circuit.

You may use a variable resistor in the meter circuit (R_2 in fig. 7-21) to compensate for variations in battery voltage. Before using an ohmmeter for a precise resistance measurement, short the leads together and set the needle to zero by rotating the "zero ohms" (variable resistor) knob. The result is a full-scale reading at zero ohms.

CAUTION

Be certain not to place the ohmmeter leads across an energized circuit or a charged capacitor. Ignoring this rule will likely result in damage to the test equipment. Always turn off the power on a circuit to be tested before making continuity or resistance tests. Before you test with an ohmmeter, bleed any capacitors that are included in the circuits under test. Use extreme care in testing solid-state components and equipment with an ohmmeter. The voltage from the internal batteries of the ohmmeter will severely damage many solid-state components. Always turn an ohmmeter off after you have completed your test to lengthen the life of the batteries.

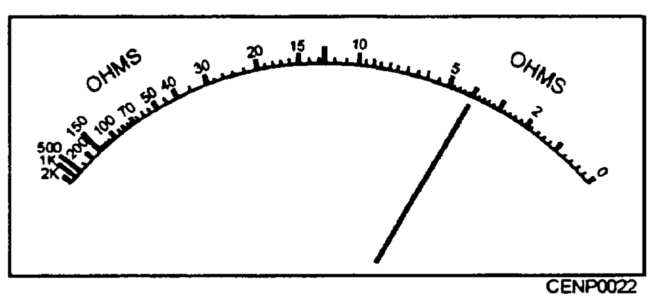


Figure 7-22.—Typical scale of a series type of ohmmeter.

After you zero the meter, place the leads across the circuit or component under test. The resistance of the unknown resistor between the ohmmeter leads limits the current through the meter, resulting in less than a full-scale deflection of the needle. The resistance reading may then be taken from the point along the scale at which the needle comes to rest

Accurate readings become progressively more difficult to take toward the high-resistance end of the scale. When the needle comes to rest at the high end of the scale and the ohmmeter has several resistance ranges, you may simply switch to a higher range for a reading closer to center scale. The resistance is read directly from the scale at the lowest range (for example, the R x 1 range on some ohmmeters). At the higher ranges the reading may be multiplied by 100 or 10,000 (as on the R x 100 or R x 1,000 ranges). The higher resistance ranges in a multirange ohmmeter use a higher voltage battery than do the lower ranges.

We will discuss multimeters (meters that perform more than one function) later in this chapter, but since we have already discussed the ammeter as a clamp-on ammeter, we will look at the same instrument as an ohmmeter.

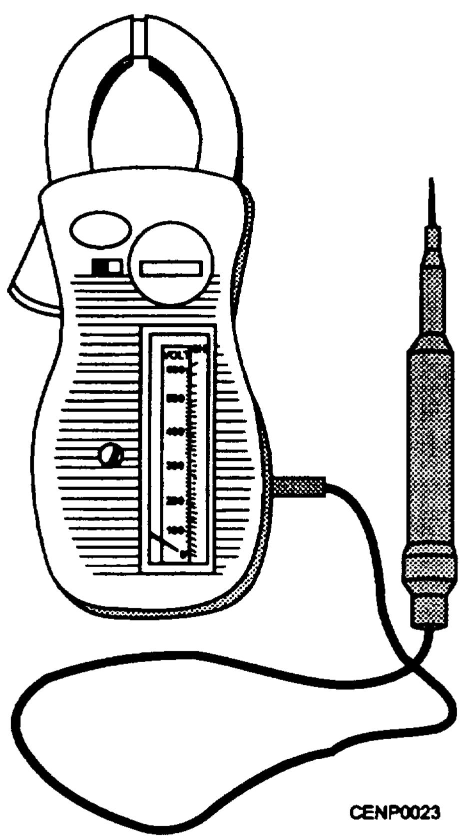


Figure 7-23.—Clamp-on ammeter with ohmmeter battery adapter.

To use the ammeter as an ohmmeter, you should plug a battery adapter into the jack on the side of the case (fig. 7-23). The battery in the adapter powers the ohmmeter function of this instrument. One of two test leads that may be plugged into the instrument (for voltage measurements) is used for the second lead of the ohmmeter. This test lead is plugged into the jack marked “COMMON.” The ohmmeter scale is a fixed scale at the right side of the scale window opening. It is not part of the rotating scale mechanism. The rotating mechanism has no effect on the ohmmeter operation. The leads are applied to the circuit or component, and the reading is taken as with any ohmmeter.

The series type of ohmmeter is only one type of instrument used for resistance measurements, but it is common in the design of ohmmeters used by Construction Electricians.

MULTIMETERS

Up to this point, each of the instruments we have discussed, for the most part, performs only one function. The exception was the clamp-on ammeter/ohmmeter. In a similar way the analog meters and digital meters perform several (or multiple) functions and are therefore referred to as multimeters.

An analog instrument usually makes use of a needle to indicate a measured quantity on a scale. Digital meters indicate the quantity directly in figures. We will discuss both types here because you will use both types.

Notice that each multimeter in figure 7-24 (A, B, C, and D) consists of a case to enclose the indicating device, one or more functions and/or range switches, and internal circuitry and jacks for external connections.

Voltage Measurements

Before plugging the test leads into the jacks, set the switches for the measurement. Let’s look at anexample. You are about to measure the voltage at a standard wall outlet in an office. You already know from experience that the voltage should be in the area of 115 to 125 volts ac. You have one of two types of multimeters-an analog meter or a digital meter. Because you do know the voltage to be tested, you would set the function switch to AC and the voltage to 250V. For the operation of the range and function switches on the particular meter, you should check the manufacture’s literature.

What should you do if you have no idea what the voltage is? There are times when you should not get

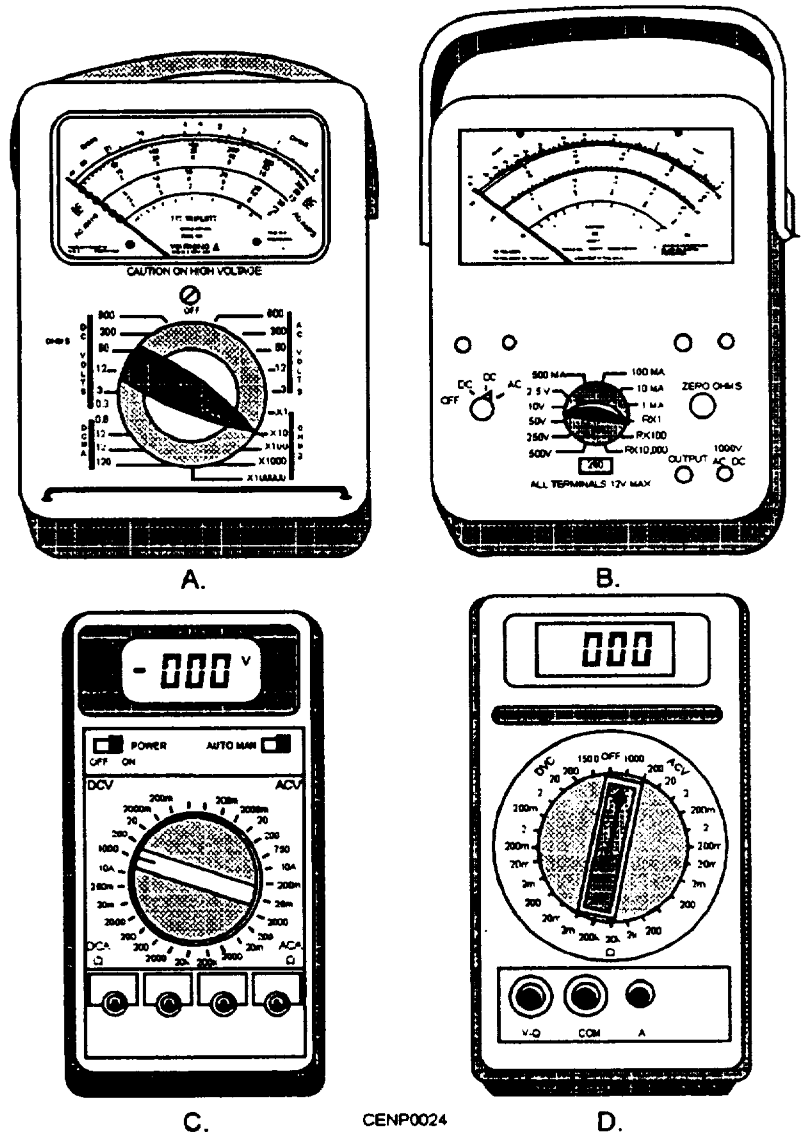


Figure 7-24.—Typical multimeters (analog types A and B and digital types C and D).

near the equipment; in this case, you should check with someone who knows (for example, a public works engineer or line crew supervisor). Check the highest range on your instrument. If you have a meter and you know the voltage value should not exceed 1,000 volts ac, then set the range/function switch to 1,000 ACV.

Plug the test leads into the appropriate jacks for the test you are about to perform. When you have red and black test leads, get into the habit of using the black lead with the common or - (negative) jack, even when measuring ac volts. For either analog meter, plug the red lead into the + (positive) jack. With either of the digital meters, use the jack marked "V-O" (volts-ohms).

WARNING

The following sequence of steps is important for your safety. Stay alert and follow them carefully.

Connect the two test leads to the two conductors/terminals of the wall outlet while holding the insulated protectors on the test leads. Do not touch the probes or clips of the test leads. Take the reading. If you have the meter range switch at the highest setting and see that the voltage value is within a lower voltage range, set the range switch to the lower range that is still higher than the voltage reading you remember. When you take a reading at a higher range and switch to a lower range, the reading at the lower range will be more accurate. Be certain to read from the scale that matches the range setting of the switch; for example, when using the multimeter with the switch set to 300 AC VOLTS, read from the scale that has a maximum reading of 300 ac. Simply take the reading directly from either of the digital multimeters.

WARNING

Always be alert when taking voltage or amperage measurements if it is necessary to move the meter. If the instrument is moved in a way that causes tension on the test leads, one or both leads may be pulled Tom the jack(s). The leads will be energized just as the circuit to which they are connected, and they can be dangerous.

The positions of the jacks may differ for a particular measurement, from one meter to another. Notice how the jacks are labeled on the instrument you use, and follow the instructions from the manufacturer of the instrument.

Amperage Measurements

It is possible that you may never use a multimeter for amperage measurements. Most multimeters are designed with quite low current ranges. The clamp-on ammeter (discussed earlier) is the most convenient portable instrument for measuring ac amperes.

Resistance Measurements

As mentioned earlier, ohmmeters have their own voltage source. This circumstance is also true of the ohmmeter function of multimeters. The size and number of batteries for different instruments vary. Usually one or more 1 1/2- to 9-volt batteries are used for resistance measurements.

As you must set up the meter to measure voltage accurately, so you must set it up for measuring resistance. If you are to measure a 120-ohms resistor, for example, set the selector switch to ohms at the appropriate range. For the analog instruments, set the switch to the R x 1 or x 1 as appropriate. Read the value from the ohms scale directly. For higher values of resistance like 1,500 ohms, for example, use the R x 100 or x 100 range. In this case, multiply the reading from the ohms scale by 100.

For all critical resistance measurements, always touch the leads together and set the indicator needle to zero with the appropriate adjustment knob. Do not let the leads touch your fingers or anything else while you are zeroing the meter.

On multimeters, use the common – (negative) and + (positive) jacks for resistance measurements.

Be certain that there is no power on the circuit or component you are to test when measuring resistance. Be sure also to discharge any capacitors associated with the circuit or component to be tested before connecting the instrument to the circuit or component

For critical measurements, make sure that only the circuit or component you are to test touches the leads while you take the reading; otherwise, the reading may be inaccurate, especially on the higher resistance ranges.

Many times you will use the ohmmeter for continuity tests. All you will want to know is whether the circuit is complete or not. You will not have to zero the meter for noncritical continuity tests. You will want to touch the leads together to see where the needle comes to rest. If the needle stops at the same place when you place the leads across the circuit, you will know the path has a low resistance. In other words you will know there is continuity through the circuit.

Construction Electricians also use other instruments for different types of resistance measurements. We will discuss these instruments next.

MEGOHMMETERS

The megohmmeter is a portable instrument consisting of an indicating ohmmeter and a source of dc voltage. The dc source can be a hand-cranked generator, a motor-driven generator, a battery-supplied power pack, or rectified dc.

The megohmmeter is commonly called a "megger" although Megger© is a registered trademark. The megger tester shown in figure 7-25 is an example of a dual-operated megohmmeter. having both a hand-cranked generator and a built-in line power supply in the same module.

Any one of the ohmmeters shown in figure 7-24 will measure several megaohms. You may wonder why they are not called megohmmeters. What is the difference between the megger and the typical ohmmeter? Does not each of them have an indicator and a dc voltage source within the instrument enclosure? The megger is capable of applying a much higher value of dc voltage to the circuit or component under test than is the typical ohmmeter. Meggers that will supply a test potential of 500 volts are common in

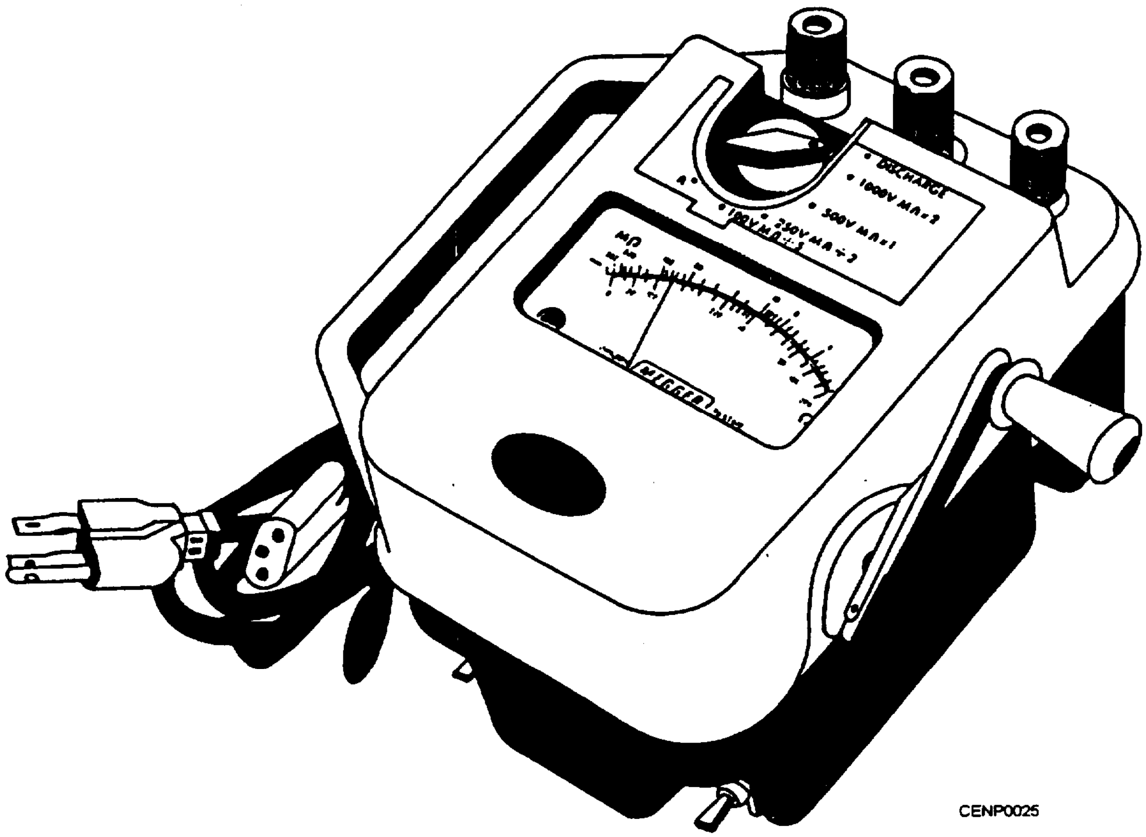


Figure 7-25.—Typical megohmmeter tester.

the Navy. The megger (fig. 7-25) is capable of several test voltages up to 1,000 volts, depending on the setting of the selector switch. Ohmmeters are generally designed to include batteries as voltage sources. These batteries apply approximately 1/2 to 9 volts to the circuit under test.

The design of the megger is such that the needle floats freely until the generator is operated. When the generator is not operating, the needle may come to rest at any point on the scale. This characteristic is due to internal design, unlike that used in the typical ohmmeter.

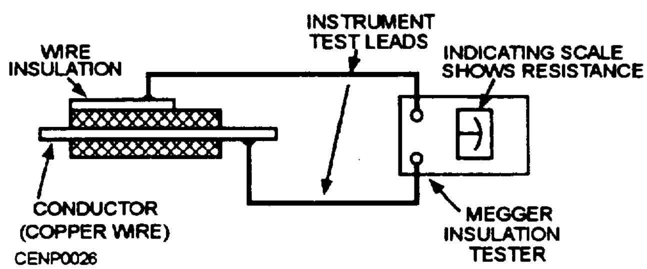


Figure 7-26.—Typical megger test instrument hooked up to measure insulation resistance.

INSULATION RESISTANCE TESTERS

The megger is used to measure high-insulation resistance. The high resistance may be between windings of a transformer or motor or between the conductor in a cable and the conduit or sheath surrounding the cable (fig. 7-26).

If the test leads connected to the line and earth terminals are open-circuited (as when they are not allowed to touch anything) and the hand-cranked generator is operated, the needle is deflected to infinity (fig. 7-27). “Infinity” means that the resistance is too high for the instrument to measure. The symbol for

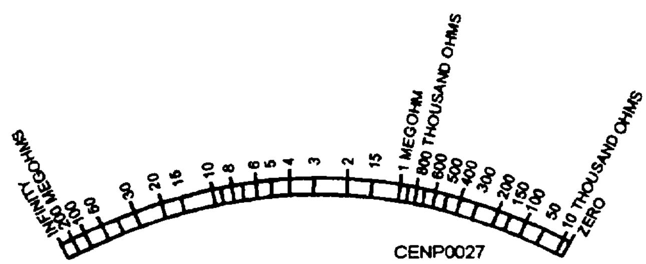


Figure 7-27.—Typical indicating scale on the megger insulation tester.

infinity on the scale of the megger (fig. 7-25) is similar to a horizontal figure eight. During a test, a reading at or near infinity means either that the insulation is in excellent shape or the test leads are not making contact with the component being tested.

If the test leads are connected to each other while the hand crank is turned, the pointer will deflect to zero, indicating no resistance between the test leads. A zero deflection in the above-mentioned test (fig. 7-26) can mean that the conductor under test is touching the sheath or conduit surrounding it. This deflection could also be an indication that the insulation is worn or broken somewhere close to the test point. Any reading near the low end of the scale may mean faulty or wet insulation.

The megger serves well as an insulation tester because of the high-test voltage it produces. The low voltage of an ohmmeter may not produce enough leakage current through poor insulation to cause the meter to indicate a problem even when one exists. But the relatively high voltage of the megger will likely cause enough leakage current to reveal an insulation problem by a lower than normal resistance indication on the meter scale.

How low is the resistance of bad insulation? How high must the insulation resistance reading be before you can be sure the insulation is good?

Here are some general observations about how you can interpret periodic insulation resistance tests, and what you should do with the results.

CONDITION	WHAT TO DO
1. Fair to high values and well maintained.	No cause for concern.
2. Fair to high values, but showing a constant tendency towards lower values.	Locate and remedy the cause and check the downward trend.
3. Low but well maintained.	Condition is probably all right, but the cause of the low values should be checked.
4. So low as to be unsafe.	Clean, dry out, or otherwise raise the values before placing equipment in service (test wet equipment while drying it out).
5. Fair or high values, previously well maintained but showing sudden lowering.	Make tests at frequent intervals until the cause of low values is located and remedied or until the values become steady at a level that is lower but safe for operation or until values become so low that it is unsafe to keep the equipment in operation.

Short-Time or Spot-Reading Tests

Several test methods are commonly used. We will discuss the short-time or spot-reading tests.

In this method, you simply connect the megger across the insulation to be tested and operate it for a short, specific time period (60 seconds usually is recommended). As shown in figure 7-28, you have picked a point (to take the reading) on a curve of increasing resistance values; quite often the value will be less for 30 seconds, more for 60 seconds. Bear in mind also that temperature and humidity, as well as condition of the insulation, affect your reading.

If the apparatus you are testing has low capacitance, such as a short run of type NM cable (Romex), the spot-reading test is all that is necessary; however, most equipment is capacitive, so your first spot reading on equipment in your work area—with no prior tests—can be only a rough guide as to how "good" or "bad" the insulation is. For many years, maintenance personnel have used the 1-megohm rule to establish the allowable lower limit for insulation resistance. The rule may be

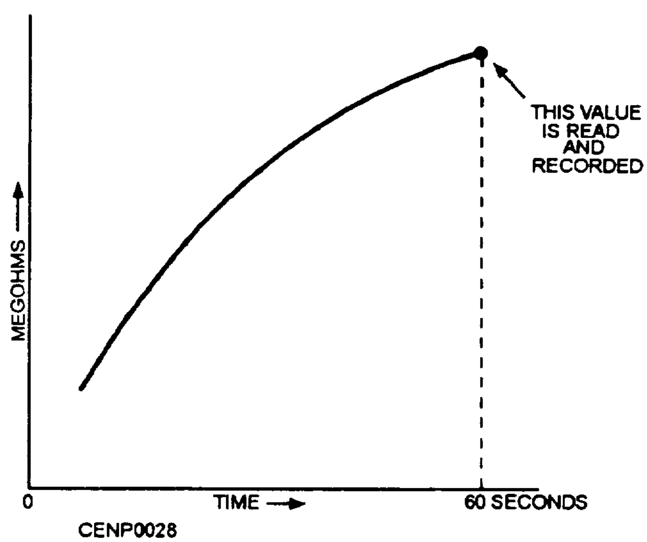


Figure 7-28.—Typical curve of insulation resistance (in megohms) with time.

stated thus: Insulation resistance should be approximately 1 megohm for each 1,000 volts of operating voltage with a minimum value of 1 megohm. For example, a motor rotated at 2,400 volts should have a minimum insulation resistance of 2.4 megohms. In practice, megohm readings normally are considerably above this minimum value in new equipment or when insulation is in good condition.

By taking readings periodically and recording them, you have a better basis for judging the actual insulation condition, Any persistent downward trend is usually fair warning of trouble ahead, even though the readings may be higher than the suggested minimum safe values. Equally true, as long as your periodic readings are consistent, they may be all right even though lower than the recommended minimum values.

Common Test Voltages

Commonly used dc test voltages for routine maintenance are as follows:

EQUIPMENT AC RATING	DC TEST VOLTAGE
	(See selector switch settings on Megger© in fig. 7-25.)
up to 100 volts	100 and 250 volts
440 to 550 volts	500 and 1,000 volts
2,400 volts	1,000 to 2,500 volts or higher
4,160 volts and above	1,000 to 5,000 volts or higher

CAUTION

Use care in applying test voltage to the component to be tested. Do not use a high-test voltage on low-voltage equipment or components.

Do not exceed the commonly used test voltages mentioned above unless you are following the equipment manufacturer's instructions to do so. On the other hand, a test voltage lower than the operating voltage of the component to be tested may not reveal a problem that the test should indicate. If the test voltage is too low, you may get no more than a resistance reading such as you would get with an ohmmeter.

Causes of Low Insulation Resistance Readings

Insulation resistance varies with the temperature. The effect of temperature depends on the type of insulation, the amount of moisture in and on the insulation surface, and the condition of the surface.

The amount of moisture in insulation has a great effect on its resistance. For meaningful results, tests of insulation resistance should be made under as nearly similar conditions as practical. Long cables can be exposed to a variety of conditions along the cable route at the same time. A comparison of readings may not indicate a change in insulation condition.

An accumulation of things like dust, dirt, and moisture can cause low-resistance readings. A motor stored or kept idle for a while may have to be cleaned and dried out before being installed and placed in service.

Record Keeping

Records should be kept where tests are performed periodically. The frequency of the tests should be based on the importance of the circuit. One test each year is usually adequate. Records of each circuit or component may be compared. Trends may indicate a future problem, and corrections may be made in time to prevent future problems in cables or components, like motors or transformers.

Effects of Temperature

If you want to make reliable comparisons between readings, you should correct the readings to a base temperature, such as 20°C (68°F), or take all your readings at approximately the same temperature (usually not difficult to do). We will cover some general guidelines to temperature correction.

One rule of thumb is that for every 10°C (50°F) increase in temperature, you halve the resistance; or for every 10°C (50°F) decrease, you double the resistance; for example, a 2-megohm resistance at 20°C (68°F) reduces to 1/2 megohm at 40°C (104°F).

Each type of insulating material will have a different degree of resistance change with temperature variation. Factors have been developed, however, to simplify the correction of resistance values. Table 7-3 gives such factors for rotating equipment, transformers, and cable. You multiply the reading you get by the factor corresponding to the temperature (which you need to measure).

For example, assume you have a motor with Class A insulation and you get a reading of 3.0 megohms at a temperature (in the windings) of 131°F (55°C). From table 7-3 you read across at 131°F to the next column (for Class A) and obtain the factor 15.50. Your correct value of resistance is then

3.0 megohms	x 15.50	= 46.5 megohms
(reading at 131°F)	(Correction factor for Class A insulation at 131°F)	(Corrected reading for 68°F or 20°C)

Note that the resistance is 14.5 times greater at 68°F (20°C) than the reading taken at 131°F. The reference temperature for cable is given as 60°F (15.6°C), but the important point is to be consistent-correcting to the same base before making comparisons between readings.

Effects of Humidity

We mentioned in this chapter about the presence of moisture in insulation and its marked effect upon resistance values. You might expect that increasing humidity (moisture content) in the surrounding (ambient) air could affect insulation resistance. And it can, to varying degrees.

If your equipment operates regularly above what is called the "dew-point" temperature (that is, the temperature at which the moisture vapor in air condenses as a liquid), the test reading normally will not be affected much by the humidity. This stability is true even if the equipment to be tested is idle, so long as its temperature is kept above the dew point. In making this point, we are assuming that the insulation surfaces are free of contaminants, such as certain lints and acids or

Table 7-3.—Temperature Correction Factors (Corrected to 20°C for Rotating Equipment and Transformers; 15.6° for Cable)

TEMP.		ROTATING EQUIP.			CABLES							
°C	°F	CLASS A	CLASS B	OIL-FILLED TRANSFORMERS	CODE NATURAL	CODE GR-S	PERFORMANCE NATURAL	HEAT RESIST. NATURAL	HEAT RESIST. & PERFORM GR-S	OZONE RESIST. NATURAL GR-S	VARNISHED CAMBRIC	IMPREGNATED PAPER
0	32	0.21	0.40	0.25	0.25	0.12	0.47	0.42	0.22	0.14	0.10	0.28
5	41	0.31	0.50	0.36	0.40	0.23	0.60	0.56	0.37	0.26	0.20	0.43
10	50	0.45	0.63	0.50	0.61	0.46	0.76	0.73	0.58	0.49	0.43	0.64
15.6	60	0.71	0.81	0.74	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20	68	1.00	1.00	1.00	1.47	1.83	1.24	1.28	1.53	1.75	1.94	1.43
25	77	1.48	1.25	1.40	2.27	3.67	1.58	1.68	2.48	3.29	4.08	2.17
30	86	2.20	1.58	1.98	3.52	7.32	2.00	2.24	4.03	6.20	8.62	3.20
35	95	3.24	2.00	2.80	5.45	14.60	2.55	2.93	6.53	11.65	18.2	4.77
40	104	4.80	2.50	3.95	8.45	29.20	3.26	3.85	10.70	25.00	38.5	7.15
45	113	7.10	3.15	5.60	13.10	54.00	4.15	5.08	17.10	41.40	81.0	10.70
50	122	10.45	3.98	7.85	20.00	116.00	5.29	6.72	27.85	78.00	170.00	16.00
55	131	15.50	5.00	11.20			6.72	8.83	45.00		345.00	24.00
60	140	22.80	6.30	15.85			8.58	11.62	73.00		775.00	36.00
65	149	34.00	7.90	22.40				15.40	118.00			
70	158	50.00	10.00	31.75				20.30	193.00			
75	167	74.00	12.60	44.70				26.60	313.00			

salts that have the property of absorbing moisture (chemists call them "hygroscopic" or "deliquescent" materials). Their presence could unpredictably affect your readings; they should be removed before tests are made.

In electrical equipment we are concerned primarily with the conditions on the exposed surfaces where moisture condenses and affects the overall resistance of the insulation. Studies show, however, that dew will form in the cracks and crevices of insulation before it is visibly evident on the surface. Dew-point measurements will give you a clue as to whether such invisible conditions may exist, altering the test results.

As a part of your maintenance records, it is a good idea to make note at least of whether the surrounding air is dry or humid when the test is made and whether the temperature is above or below the ambient. When you test vital equipment, record the ambient wet- and dry-bulb temperatures from which dew point and percent relative or absolute humidity can be obtained

Preparation of Apparatus for Test

NOTE: Before interrupting any power, be certain to check with your seniors (crew leader, project chief, or engineering officer, as appropriate) so that any necessary notification of the power outage may be made. Critical circuits and systems may require several days or even weeks advance notice before authorization for a power outage may be granted.

TAKE OUT OF SERVICE.—Shut down the apparatus you intend to work on. Open the switches to de-energize the apparatus. Disconnect it from other equipment and circuits, including neutral and protective (workmen’s temporary) ground connections. See the safety precautions that follow in this section.

MAKE SURE OF WHAT IS INCLUDED IN THE TEST.—Inspect the installation carefully to determine just what equipment is connected and will be included in the test, especially if it is difficult or expensive to disconnect associated apparatus and circuits. Pay particular attention to conductors that lead away from the installation. That is important, because the more equipment that is included in a test, the lower the reading will be, and the true insulation resistance of the apparatus in question may be masked by that of the associated equipment.

WARNING

Care should be taken in making electrical insulation tests to avoid the danger of electric shock. Read and understand the manufacturer’s safety precautions before using any megohmmeter. As with the ohmmeter, never connect a megger to energized lines or apparatus. Never use a megger or its leads or accessories for any purpose not described in the manufacturer’s literature. If in doubt about any safety aspects of testing, ask for help. Other safety precautions will follow in this section.

Safety Precautions

WARNING

Observe all safety rules when taking equipment out of service.

- Block out disconnect switches.
- Be sure equipment is not live.
- Test for foreign or induced voltages.
- Ensure that all equipment is and remains grounded—both equipment that you are working on and other related equipment.
- Use rubber gloves when required.
- Discharge capacitance fully.
- Do not use the megger insulation tester in an explosive atmosphere.

When taking equipment out of service, be sure to observe all rules for safety. Block out the disconnect switches. Test for foreign or induced voltages. Apply workmen’s grounds. (Workmen’s grounds are grounds you or others use to ground equipment while you are working on it;)

When you are working around high-voltage equipment, remember that because of proximity to energized high-voltage equipment, there is always a possibility of voltages being induced in apparatus under test or lines to which it is connected; therefore, rather than removing a workmen’s ground to make a test, you should disconnect the apparatus, such as a transformer or circuit breaker, from the exposed bus or line, leaving the latter grounded. USE RUBBER GLOVES WHEN CONNECTING THE TEST LEADS TO THE APPARATUS AND WHEN OPERATING THE MEGGER.

APPARATUS UNDER TEST MUST NOT BE LIVE.—If neutral or other ground connections have to be disconnected, make sure that they are not carrying current at the time and that when they are disconnected, no other equipment will lack protection normally provided by the ground.

Pay particular attention to conductors that lead away from the circuit being tested and make sure that they have been properly disconnected from any source of voltage.

SHOCK HAZARD FROM TEST VOLTAGE.—Observe the voltage rating of the megger and regard it with appropriate caution. Large electrical equipment and cables usually have sufficient capacitance to store up a dangerous amount of energy from the test current. Make sure this capacitance is discharged after the test and before you handle the test leads.

DISCHARGE OF CAPACITANCE.—It is very important that capacitance be discharged, both before and after an insulation resistance test. It should be discharged for a period about four times as long as test voltage was applied in a previous test.

Megger instruments are frequently equipped with discharge switches for this purpose. If a discharge position is not provided, a discharge stick should be used. Leave high capacitive apparatus (for instance, capacitors, large windings, etc.) short circuited until you are ready to re-energize it.

EXPLOSION AND FIRE HAZARD.—So far as is known, there is no fire hazard in the normal use of a megger insulation tester. There is, however, a hazard when your test equipment is located in a flammable or explosive atmosphere. Slight sparking may be encountered (1) when you are attaching the test leads to equipment in which the capacitance has not been completely discharged, (2) through the occurrence of arcing through or over faulty insulation during a test, and (3) during the discharge of capacitance following a test. Therefore:

WARNING

Do NOT use the megger insulation tester in an explosive atmosphere.

Suggestions: For (1) and (3) in the above paragraph, arrange permanently installed grounding facilities and test leads to a point where instrument connections can be made in a safe atmosphere.

For (2): Use low-voltage testing instruments or a series resistance.

For (3): To allow time for capacitance discharge, do not disconnect the test leads for at least 30 to 60 seconds following a test.

MOTORS AND CONTROLS

As a Construction Electrician, you must understand the principles of operation and construction of electrical motors and controllers. This knowledge is necessary so you can perform troubleshooting, maintenance, and repair of this equipment. You must be able to determine why the motor or controller is inoperative, if it can be repaired without removing it from service, or if it must be replaced. You must know what equipment substitutions or replacements to make and how to make the proper lead connections. The various types of motors and controllers have many elements in common; therefore, maintenance is fairly uniform. Once a motor or controller has been installed and the proper maintenance performed, you will have very little trouble. However, if something should go wrong, you must understand motors and controllers and how they operate to determine what troubleshooting steps to take and repairs to make. Remember, YOU are the repairman.

MOTORS

Motors operate on the principle that two magnetic fields within certain prescribed areas react upon each other. Pole pieces, frame, and field coils form one field; and as current is sent through the armature windings, another magnetic field is set up. The units of a motor, then, are the poles and the armature. The poles are ordinarily the static part, and the armature is the rotating Part

The poles are formed by placing magnetized bars so that the north pole of one is placed directly opposite of the south pole of the other. The air gap between these poles contains the magnetic field Just as a conductor must be insulated to prevent its electrical charge from being grounded, so the magnetic field must be shielded from the earth's magnetic field, or from the field of nearby generators or motors. This shielding is usually accomplished by surrounding the field with a shell of soft iron. The armature carries the coils which cut the lines of force in the field.

DC MOTORS AND CONTROLS

Direct-current motors and controls are seldom installed, maintained, or serviced by CEs unless they are assigned to special units, such as the State Department, where they will receive special training on this type of equipment. Therefore, we will not go into the depth on dc motors and controls as we will with ac. For information on direct-current motors and controls refer to the Navy Electricity and Electronics Training

Series (NEETS) modules and the *Electrician's Mate* Training Manual, NAVEDTRA 12164.

AC MOTORS

Most of your work with motors, at shore stations especially, will be with a-c motors. Dc motors have certain advantages but a-c power is more widely used and a-c motors are less expensive and on the whole, more reliable.

For example, sparking at the brushes of a dc motor can be very dangerous if there is explosive gas or dust in the surrounding air. On most a-c motors, brushes and commutators are not used and little maintenance is required. They are suited to constant speed applications and are designed to operate at a different number of phases and voltages.

A-c motors are designed in various sixes, shapes, and types such as the induction, series, and synchronous, but as a Construction Electrician in the U. S. Navy, you will be concerned primarily with the induction motors. This type of motor includes, among others, the split-phase, capacitor, repulsion-induction, and the polyphase motors.

SPLIT-PHASE MOTORS

A split-phase motor is usually of fractional horsepower. It is used to operate such devices as small pumps, oil burners, and washing machines. It has four main parts. These are the rotor, the stator, the end plates (or end bells, as they are sometimes called), and a centrifugal switch

The rotor consists of three parts. One of these parts is the core which is made up of sheets of sheet steel called laminations. Another part is a shaft on which these laminations are pressed. The third part is a squirrel-cage winding consisting of copper bars which are placed in slots in the iron core and connected to each other by means of copper rings located on both ends of the core. In some motors the rotor has a one-piece cast aluminum winding.

The stator of a split-phase motor consists of a laminated iron core with semiclosed slots, a steel frame into which the core is pressed, and two windings of insulated copper wire that are placed into the slots and are called the running and starting windings.

End bells, which are fastened to the motor frame by means of bolts or screws, serve to keep the rotor in perfect alignment. These end bells are equipped with bores or wells in the center, and are fitted with either sleeve or ball bearings to support the weight of the rotor and thus permit it to rotate without rubbing on the stator.

The centrifugal switch is located inside the motor on one of the end bells. It is used to disconnect the starting winding after the rotor has reached a predetermined speed, usually 75 percent of the full load speed. The action of the centrifugal switch is as follows: the contacts on the stationary part of the switch (the stationary part is mounted on the end bell) are closed when the motor is not in motion and make contact with the starting winding. When the motor is energized and reaches approximately 75 percent of full load speed, the rotating part of the switch (mounted on the rotor) is forced by centrifugal force against the stationary arm, thereby breaking the contact and disconnecting the starting winding from the circuit. The motor is then operating on the running winding as an induction motor. Figure 7-29 shows the two major parts of a centrifugal switch.

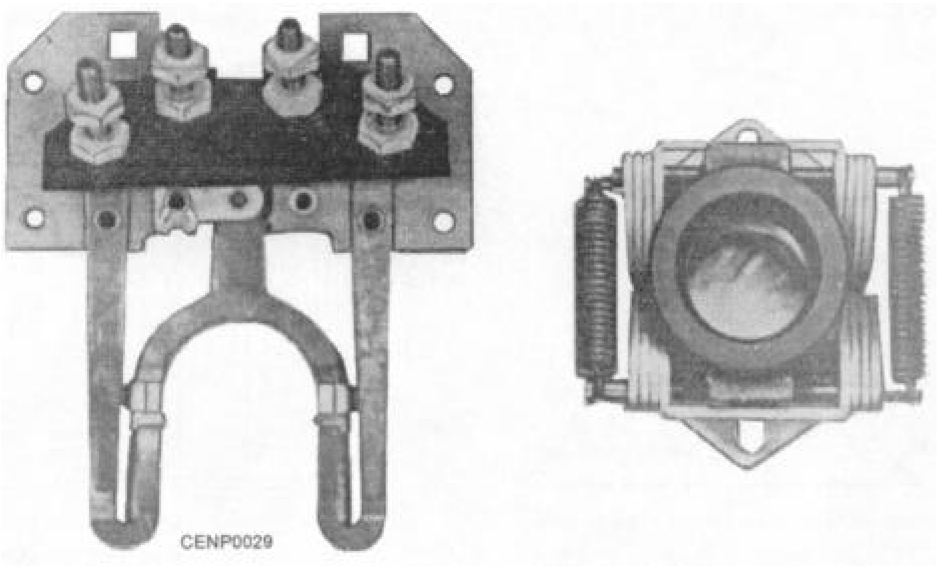


Figure 7-29.—Two major parts of a centrifugal switch.

The direction of rotation of a split-phase motor may be reversed by reversing the connections leading to the starting winding. This action can usually be done on the terminal block in the motor. Figure 7-30 shows a diagram of the connections of a split-phase motor.

Troubleshooting and Repair

Motors require occasional repairs, but many of these can be eliminated by following a preventive maintenance schedule. Preventive maintenance, in simple terms, means taking care of the trouble before it happens. For example, oiling, greasing, cleaning, keeping the area around the equipment clean, and seeing that the equipment has the proper protective fuses and overload protection are preventive maintenance steps that eliminate costly repairs.

To analyze motor troubles in a split-phase motor, the first check is for proper voltage at the terminal block. If you have the proper voltage, check the end bells for cracks and for alignment. The bolts or screws may be loose and the ends may be out of line. The next check is for a ground With the motor disconnected, check the connections from the terminal block to the frame with an ohmmeter or megger. If you find a ground in this test, remove the end bell with the terminal block and centrifugal switch and separate the starting winding and running winding and make another ground check on each of these windings. In many cases you will find the ground in the loops where the wires are carried from one slot to the next one. This situation can sometimes be repaired without removing the winding. In some cases, the ground may be in the centrifugal switch due to grease that has accumulated from over-greasing.

If the first test does not show a ground in the motor, check to see that the rotor revolves freely. If the rotor turns freely connect the motor to the source of power and again check to see that the rotor turns freely when energized. If the rotor turns freely with no voltage applied, but locks when it is applied, you will know that the bearings are worn enough to allow the iron in the rotor to make contact with the iron in the pole pieces.

If the trouble is a short, either the fuse will blow or the winding will smoke when the motor is connected to the line. In either event the motor will have to be disassembled A burned winding is easily recognizable by its smell and the burned appearance. The only remedy is to replace the winding. If the starting winding is burned, it can usually be replaced without disturbing the running winding, but check closely to be sure that the running winding is not damaged. In making a check for a shorted coil, the proper procedure is to use an ohmmeter to check the resistance in the coil that you suspect to be bad. Then check this reading against a reading from a coil that is known to be good.

An open circuit can be caused by a break in a wire in the winding, or by the centrifugal switch not closing properly when the motor is at a standstill. Too much end play in the rotor shaft may cause the rotating part of the centrifugal switch to stop at a point where it allows the contacts on the stationary part of the switch to stand open. Should the rotor have more than 1/64-inch end play, place fiber washers on the shaft to line the rotor up properly.

If the motor windings are severely damaged, the motor must be sent to a motor shop for repairs. The repairs will usually be done in a shop operated by Public Works or the motor may be sent outside the base to a civilian operated motor shop. For this reason only the basic principles of the winding procedure will be covered.

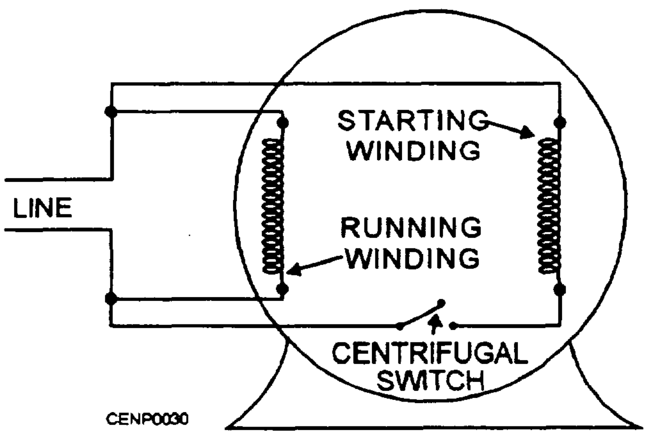


Figure 7-30.—Diagram of the connections of a split-phase motor.

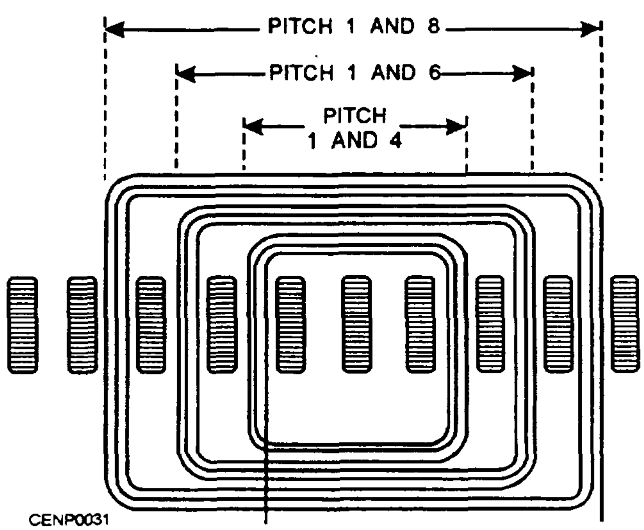


Figure 7-31.—The pitch of a coil.

Repair of a split-phase motor with a damaged winding consists of several operations: taking the winding data, stripping the old windings, insulating the slots, winding the coils and placing them in the slots, connecting the windings, testing, varnishing and baking the winding.

Before the motor is taken apart, the end plates should be marked with a center punch so that they may be reassembled properly. One punch mark should be put on the front end plate and a corresponding mark made on the frame. Two marks should be made on the opposite end plate and also on the frame at that point.

Taking the winding data is one of the most important parts of the operation This action consists of obtaining and recording information concerning the old winding; namely, the number of poles, the pitch of the coil (the number of slots that each coil spans), (fig. 7-31), the number of turns in each coil, the size of the wire in each winding, the type of connection (series or parallel), the type of winding, and slot insulation. See figure 7-32.

This data is taken while removing the old winding from the motor frame. One coil should be cut at a place where the number of turns may be counted. The size of the wire and other data is then entered on the data sheet.

SPLIT PHASE MOTOR DATA

MAKE			
HP	RPM	VOLTS	AMPS
CYCLE	TYPE	FRAME	STYLE
TEMP	MODEL	SERIAL NO	PHASE

NO OF POLES	END ROOM	NO OF SLOTS

LEAD PITCH	COMMUTATOR PITCH
WIRE INSULATION	WINDING (HAND, FORM, AND SKEIN)

SLOT INSULATION	TYPE	SIZE	THICKNESS

TYPE CONNECTIONS	SWITCH	LINE

WINDING	TYPE	SIZE AND KIND WIRE	NO OF CIRCUITS	COIL PITCH	TURNS
RUNNING					
STARTING					

SLOT NO	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
RUNNING																																					
STARTING																																					

ROTATION	CLOCKWISE	COUNTER CLOCKWISE

CENP0032

Figure 7-32.—Split-phase motor data sheet.

Clean the old insulation and varnish from the slots before installing the new slot insulators. This cleaning is usually done with a torch. The slot insulators are formed from one of several types of material available for this purpose. The best procedure is to reinsulate the slots with the same type and size insulation that was used in the original winding.

The coils are then wound according to the data sheet and replaced in the slots in the same position as the windings that were removed. The starting windings are ALWAYS placed 90 electrical degrees out of phase with the running windings.

When all the connections between the poles of the windings have been completed and tested and the leads attached, the stator should be placed in a baking oven at a temperature of about 250°F and baked for three hours to remove any trace of moisture. Heating the windings also helps the varnish to penetrate the coils.

The stator is then dipped in a good grade of insulating varnish, allowed to drip for about an hour and then placed in the oven and baked for several hours.

When the stator is removed from the oven, the inner surface of the core of the stator should be scraped to remove the varnish so that the rotor will have sufficient space to rotate freely.

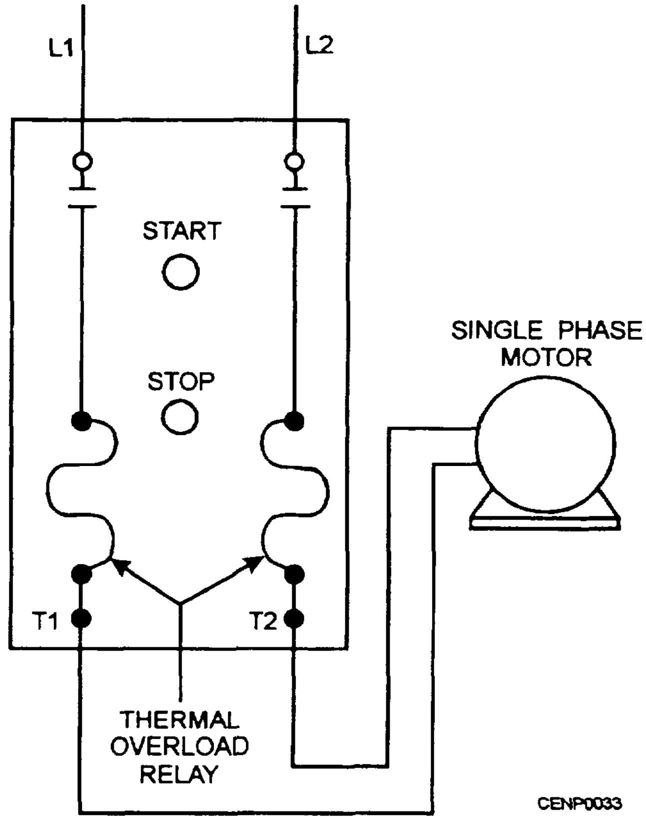


Figure 7-33.—Starting switch for a single-phase motor.

Control for a Split-Phase Motor

The control switch for a split-phase motor is usually a simple OFF and ON switch if the motor is equipped with an overload device. If the motor does not have this overload device, the switch will be of a type illustrated in figure 7-33. This type of switch has two push buttons; one to start and one to stop the motor. It uses interchangeable thermal overload relay heaters for protection of various size motors. In some cases, a 30-ampere safety switch with the proper size fuse may be used.

CAPACITOR MOTORS

The capacitor motor is similar to the split-phase motor, but an additional unit, called a capacitor, is connected in series with the starting winding, These motors may be of capacitor-start or the capacitor-run type.

The capacitor is usually installed on top of the motor; but it may be mounted on the end of the motor frame, or inside the motor housing, or remote from the motor. Acapacitor acts essentially as a storage unit. All capacitors have this quality and all are electrically the same. The only difference is in the construction The type of capacitor usually used in fractional-horsepower motors is the paper capacitor. This type of capacitor has strips of metal foil separated by an insulator, usually waxed paper. The strips are rolled or folded into a compact unit which is placed in a metal container either rectangular or cylindrical in shape. ‘Iwo terminals are provided for connections.

The capacitor-start motor has, like the split-phase motor, a centrifugal switch which opens the starting winding when the rotor has reached the predetermined speed, while the capacitor-run motor does not have the centrifugal switch and the starting winding stays in the circuit at all times. Figure 7-34 shows a capacitor-start motor winding circuit. The capacitor motor provides a higher starting torque with a lower starting current than the split-phase motor.

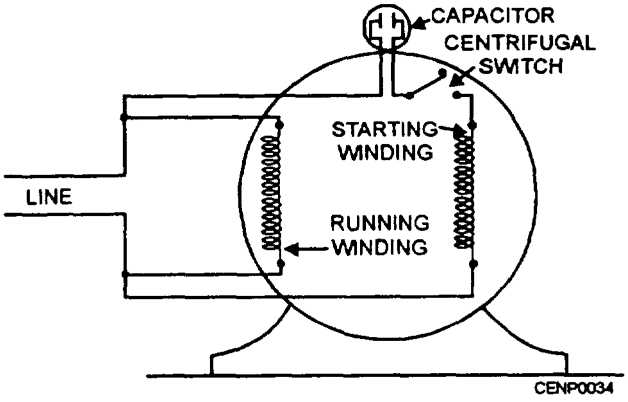


Figure 7-34.—Capacitor start motor winding circuit.

TROUBLESHOOTING AND REPAIR

The procedure for troubleshooting and repair for the capacitor motor is the same as for the split-phase motor except for the capacitor. Capacitors are rated in microfarads and are made in various ratings, according to the size and type. Acapacitor may be defective due to moisture, overheating or other conditions. In such a case it must be replaced with another one of the same value of capacity. To test a capacitor, remove the motor leads from the capacitor and connect the capacitor in series with a 10-amp fuse across a 110- volt line. If the fuse burns out, the capacitor is short-circuited and must be replaced. If the fuse does not burn out, leave the capacitor connected to the line for a few seconds to build up a charge. Do not touch the terminals after the charging process as serious injury may result from the stored charge.

Short the terminals with an insulated handle screw driver. A strong spark should show if the capacitor is good. If no spark or a weak spark results, the capacitor must be replaced.

The procedure for rewinding a capacitor motor is the same as for the split-phase motor except for the capacitor.

UNIVERSAL MOTORS

A universal motor is one that operates on either single-phase ac or dc power. These motors are normally made in sizes ranging from 1/200 to 1/3 horsepower. You can get them in larger sizes for special conditions. The fractional horsepower sizes are used on vacuum cleaners, sewing machines, food mixers, and power hand tools.

The salient-pole type is the most popular type of universal motor. The salient-pole type consists of a stator with two concentrated field windings, a wound rotor, a commutator, and brushes. The stator and rotor windings in this motor are connected in series with the power source. There are two carbon brushes that remain on the commutator at all times. These two brushes are used to connect the rotor windings in series with the field windings and the power source (fig. 7-35). The universal motor does not operate at a constant speed. The motor runs as fast as the load permits; i.e., low speed with a heavy load and high speed with a light load. Universal motors have the highest horsepower-to-weight ratio of all the types of electric motors.

The operation of a universal motor is much like a series dc motor. Since the field winding and armature are connected in series, both the field winding and armature winding are energized when voltage is applied to the motor. Both windings produce magnetic fields which react to each other and cause the armature to rotate. The reaction between magnetic fields is caused by either ac or dc power.

SHADED-POLE MOTORS

The shaded-pole motor is a single-phase induction motor that uses its own method to produce starting torque. Instead of a separate winding like the split-phase and capacitor motors, the shaded-pole motor’s start winding consists of a copper band across one tip of

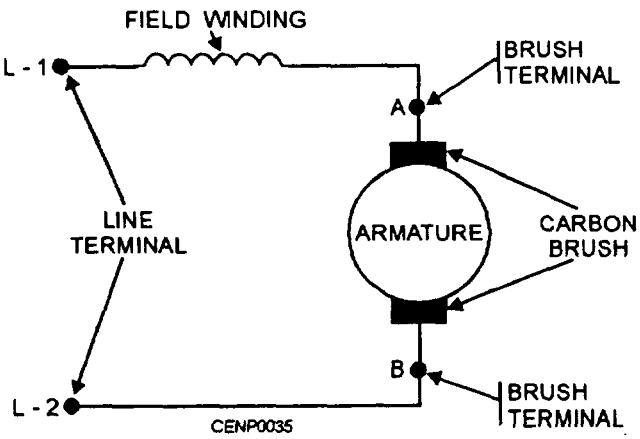


Figure 7-35.—Universal motor schematic.

each stator pole (fig. 7-36). This copper band delays the magnetic field through that portion of the pole. When ac power is applied, the main pole reaches its polarity before the shaded portion of the pole. This action causes the shaded poles to be out of phase with the main poles and a weak rotating magnetic field is produced. Because of the low-starting torque, it isn't feasible to build motors of this type larger than 1/20 horsepower. They are used with small fans, timers, and various light-load control devices.

Remember, all single-phase induction motors have some auxiliary means to provide the motor with starting torque. The method used for this starting torque depends on the application of the motor.

FAN MOTORS

A wide variety of motors are used for fans and blowers. Here we will discuss the different methods of varying the speed of common fan motors.

Different manufacturers use different methods for varying the speed. On some motors only the running-winding voltage is varied while the voltage in the starting winding is constant On others the running winding consists of two sections connected in series across 230 volts for high speed. If low speed is required, the two sections are connected to 155 volts through an auto-transformer. Usually, these motors are connected for three speeds.

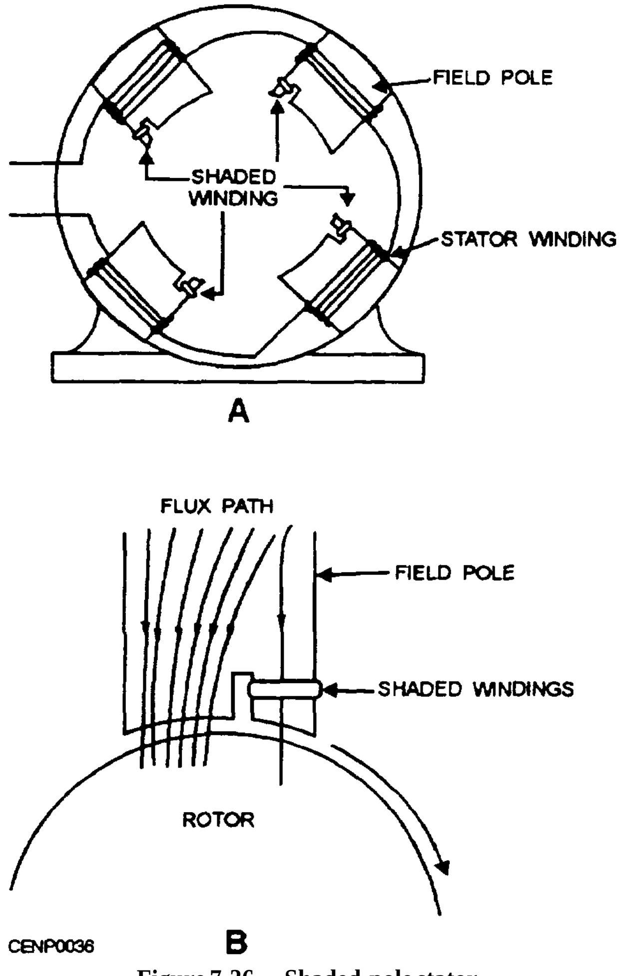


Figure 7-36.—Shaded-pole stator.

SPEED CONTROL OF SHADED POLE MOTORS

Many fans have a shaded-pole type motor. The speed of these motors is varied by inserting a choke coil in series with the main winding. Taps on the choke coil provide the different speeds.

SPEED CONTROL OF SPLIT-PHASE AND CAPACITOR MOTORS

Split-phase and capacitor motors are commonly used in floor and wall fans. Two-speed, split-phase, motors are normally made with two run windings and either one or two start windings, depending on the manufacturer. In a three-speed, split-phase motor, the speeds are obtained with only three windings: one running, one auxiliary, and one starting winding. For high speed, the running winding is connected across the line, and the starting winding is connected in series with the auxiliary winding across the line. For medium speed, the running winding is connected in series with half the auxiliary winding, and the starting winding is connected in series with the other half of the auxiliary winding. For low speed, the running and auxiliary windings are in series across the line, and the starting winding is connected across the line. Actually, a tap at the inside point of the auxiliary is brought out for medium speed. A centrifugal switch is connected in series with the starting winding.

The capacitor motor used for two-speed floor fans is a permanent-split capacitor motor. This motor does not use a centrifugal switch. For three speeds, the auxiliary winding is tapped at the center point, and a lead is brought out for medium speed. This motor is similar to the three-speed, split-phase motor, except that the centrifugal switch is removed and a capacitor substituted. This motor is used extensively for blowers in air-conditioning systems.

Split-phase motors used on wall fans are wound like the ordinary split-phase motor, but many do not have a centrifugal switch. A special type of autotransformer, located in the base of the fan, is used to change the speed and also to produce an out-of-phase current in the starting winding. The primary of the transformer is

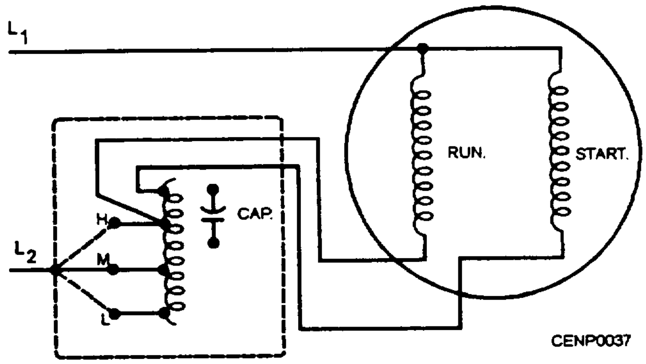


Figure 7-37.—Capacitor motor used for a wall fan.

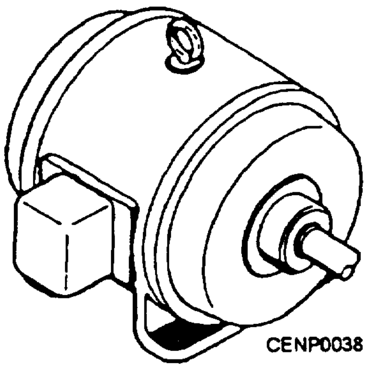


Figure 7-38.—Three-phase motor.

tapped for different speeds and is connected in series with the main winding. The starting winding is connected across the transformer secondary.

Acapacitor motor for a wall fan (fig. 7-37) contains a capacitor of approximately 1 microfarad (µf) in the starting-winding circuit. To increase the effective capacity and consequently the starting torque of this motor, connect the capacitor. across an autotransformer. The taps on the transformer permit a choice of various speeds.

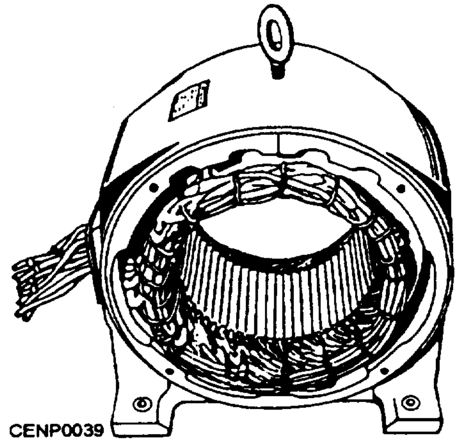


Figure 7-39.—Three-phase stator.

SPEED CONTROL OF UNIVERSAL FAN MOTORS

The universal fan motor has a resistance unit in the base to vary the speed. A lever that extends outside the base is used to insert the resistance in the circuit.

CONSTRUCTION OF THREE-PHASE MOTORS

Construction of a three-phase motor consists of three main parts: stator, rotor, and end bells. Its construction is similar to a split-phase motor, but the three-phase motor has no centrifugal switch (fig. 7-38).

STATOR

The stator, as shown in figure 7-39, consists of a frame and a laminated steel core, like that used in split-phase and repulsion motors, and a winding formed of individual coils, placed in slots.

ROTOR

The rotor may be a die-cast aluminum squirrel-cage type or a wound type. Both types contain a laminated core pressed onto a shaft. The squirrel-cage rotor (fig. 7-40) is like the rotor of a split-phase motor. The wound

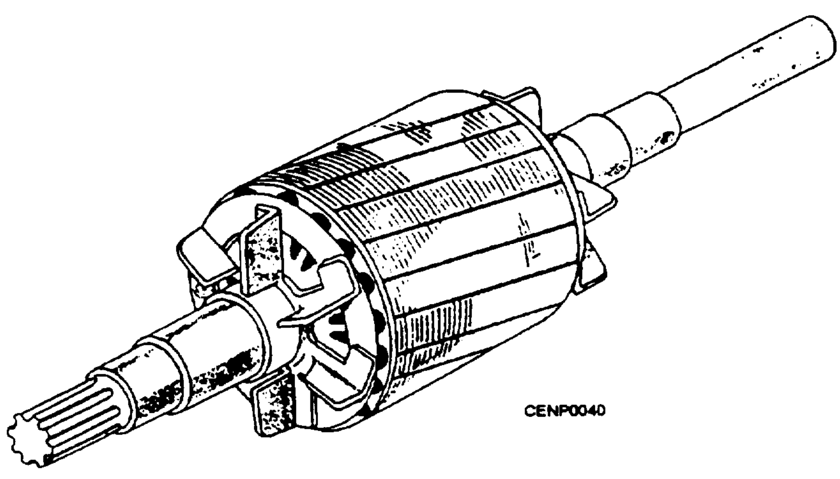


Figure 7-40.—Squirrel-cage rotor.

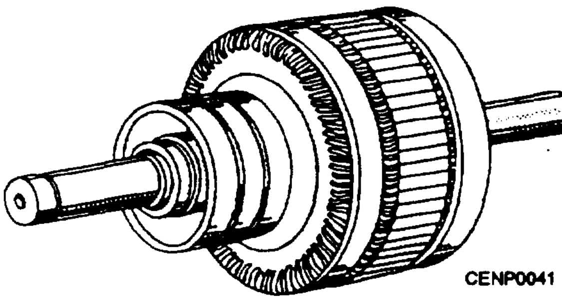


Figure 7-41.—Three-phase wound rotor.

rotor (fig. 7-41) has a winding on the core that is connected to three slip rings mounted on the shaft.

END BELLS

The end bells, or brackets, are bolted to each end of the stator frame and contain the bearings in which the shaft revolves. Either ball bearings or sleeve bearings are used for this purpose.

CONNECTING THREE-PHASE MOTORS

Connecting a three-phase motor is a simple operation. All three-phase motors are wound with a number of coils, with a 2-to-1 ratio of slots to coils. These coils are connected to produce three separate windings called phases, and each must have the same number of coils. The number of coils in each phase must be one-third the total number of coils in the stator. Therefore, if a three-phase motor has 36 coils, each phase will have 12 coils. These phases are usually called Phase A, Phase B, and Phase C. All three-phase motors have their phases arranged in either a wye connection or a delta connection.

WYE CONNECTION

A wye-connected three-phase motor is one in which the ends of each phase are joined together paralleling the windings. The beginning of each phase is connected to the line. Figure 7-42 shows the wye connection.

DELTA CONNECTION

A delta connection is one in which the end of each phase is connected in series with the next phase. Figure 7-43 shows the end of Phase A connected to the beginning of Phase B. The end of Phase B is connected to the beginning of Phase C, and the end of Phase C is connected to the beginning of Phase A. At each connection, a wire is brought out to the line.

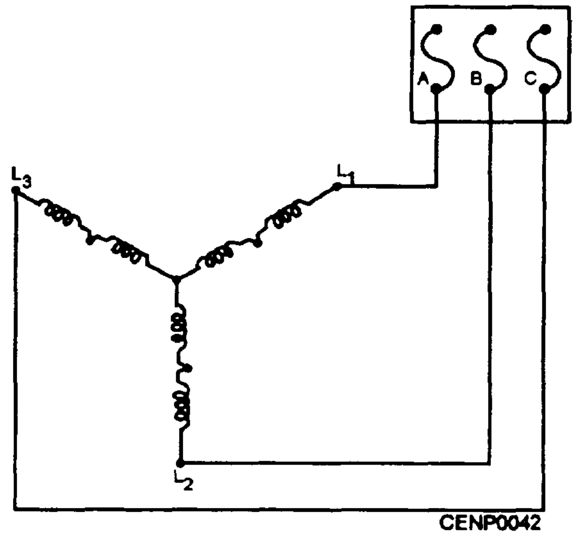


Figure 7-42.—Star, or wye, connection.

VOLTAGES

Most small- and medium-sized three-phase motors are made so that they can be connected for two voltages. The purpose in making dual-voltage motors is to enable the same motor to be used in facilities with different service voltages. Figure 7-44 shows four coils which, if connected in series, may be used on a 460-volt ac power

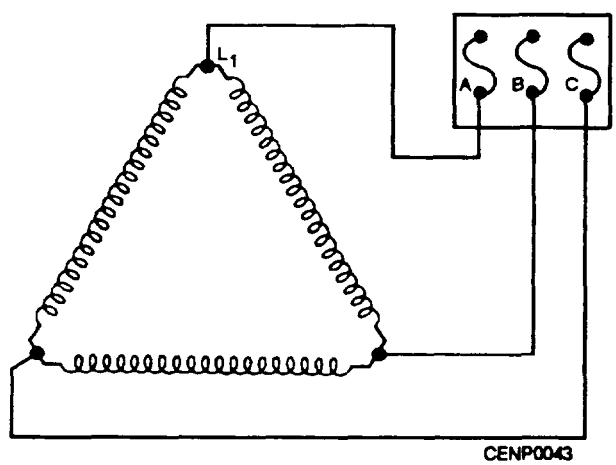


Figure 7-43.—Delta connection.

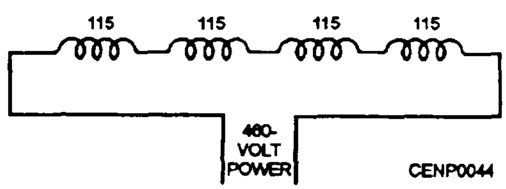


Figure 7-44.—Four 115-volt coil connected in series to produce 460 volts.

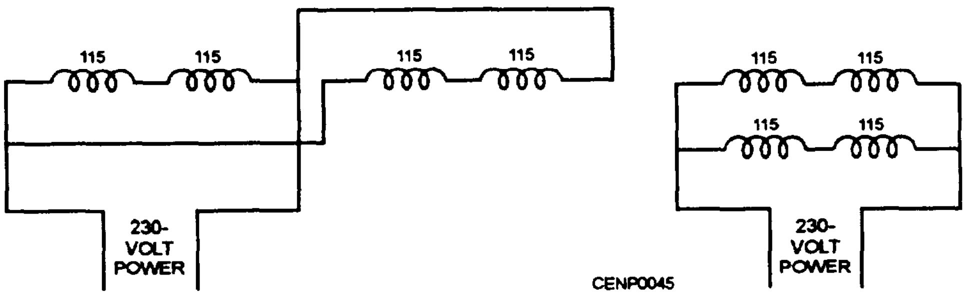


Figure 7-45.—Four 115-volt coil connected in parallel for 230 volts; each coil still receives only 115 volts.

supply. Each coil receives 115 volts. If the four coils were connected in two parallel sets of coils to a 230-volt line, as shown in figure 7-45, each coil would still receive 115 volts. So, regardless of the line voltage, the coil voltage is the same. This is the principle used in all dual-voltage machines. Therefore, if four leads are brought out of a single-phase motor designed for 460/230 or 230/115-volt operation, the motor can be readily connected for either voltage.

Dual-Voltage Wye Motor

When you are connecting a dual-voltage wye motor, remember practically all three-phase dual-voltage motors have nine leads brought out of the motor from the winding. These are marked TI through T9, so that they may be connected externally for either of the two voltages. These are standard terminal markings and are shown in figure 7-46 for wye-connected motors.

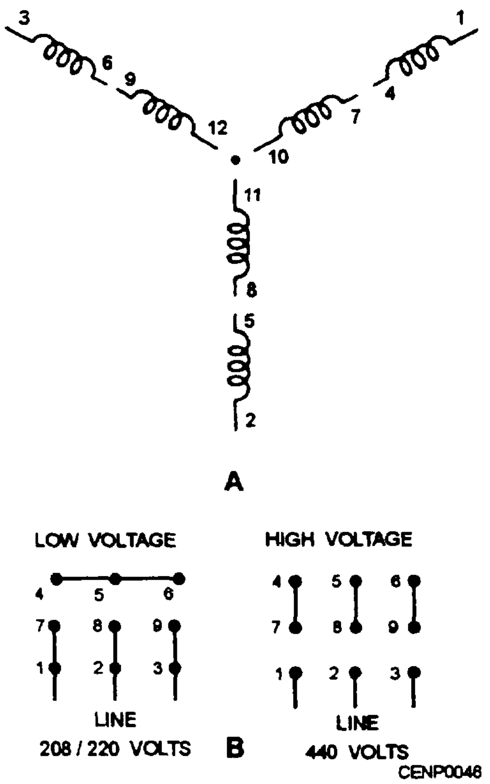


Figure 7-46.—Terminal markings and connection for a wye-connected dual-voltage motor.

HIGH VOLTAGE.—to connect for high voltage, you should connect groups in series, as shown in figure 7-47. Use the following procedure:

1. Connect T6 and T9; twist and wire nut.
2. Connect leads T4 and T7; twist and wire nut.
3. Connect T5 and T8; twist and wire nut.
4. Connect leads TI, T2, and T3 to the three-phase line.

LOW VOLTAGE.—This same motor can be connected for low voltage. Use the following procedure:

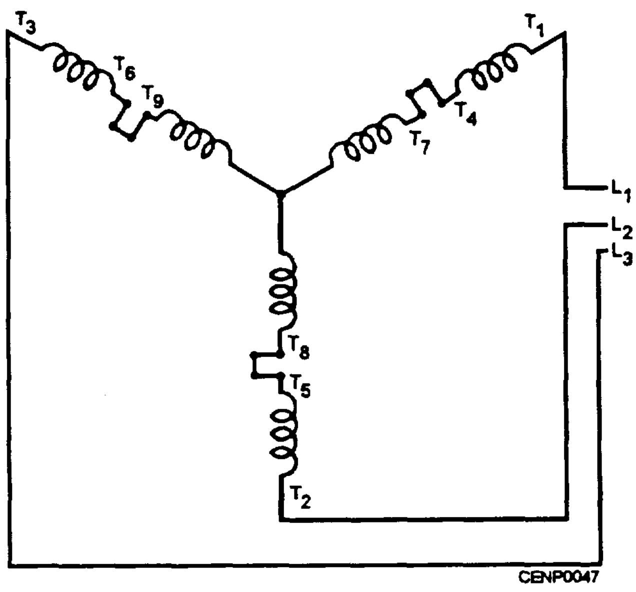


Figure 7-47.—Two-voltage wye motor windings connected in serifs for high-voltage operations.

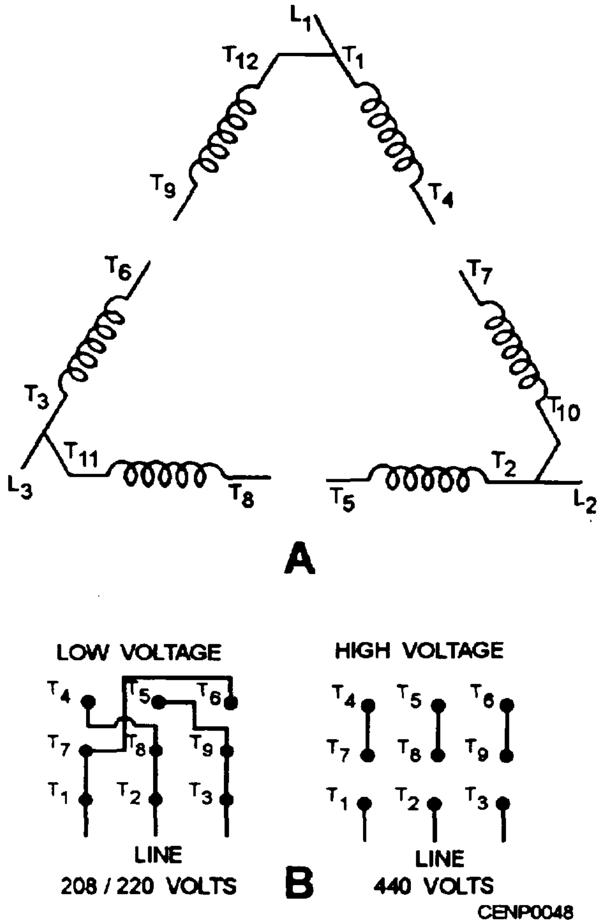


Figure 7-48.—Standard markings and connections for a delta-connected dual-voltage motor.

1. Connect lead T7 to TI and to line lead LI.
2. Connect lead T8 to T2 and to line lead L2.
3. Connect lead T3 to T9 and line lead L3.
4. Connect T4, T5. and T6 together.

Dual-Voltage Delta Motor

For connecting a dual-voltage delta motor, refer to figure 7-48 for the standard terminal markings of a dual-voltage, delta-connected motor

HIGH VOLTAGE.—For high-voltage operation, connect lead T4 to T7; connect lead T5 to T8; connect lead T6 to T9; connect T1, T2, and T3 to LI, L2, and L3, respectively.

LOW VOLTAGE.—For low-voltage operation, connect leads Tl, T7, and T6 to the line lead LI. Connect leads T2, T4, and T8 to line lead L2. Connect leads T3, T5, and T9 to line lead L3.

Reversing Three-Phase Motors

For reversing three-phase motors, figure 7-49 shows the three leads of a three-phase motor connected to a three-phase power line for clockwise rotation. To reverse any three-phase motor, interchange any two of the power leads.

AC MOTOR CONTROLLERS

This section covers common electric controllers. The term controller includes any switch or device normally used to start or stop a motor.

Controllers are classified as either manual or magnetic. The manual controller uses a toggle mechanism, moved by hand, to open or close the circuit. It may be a switch, a disconnect, or even an attachment plug. Magnetic controllers use a magnetic coil to move the mechanism which opens or closes the circuit. Magnetic controllers are operated manually by pressure on a button or automatically by a pressure switch or a similar device. The controller must be within sight of the motor, unless the disconnect device or the controller can be locked in the open position, or the branch circuit can serve as a controller. A distance of more than 50 feet is considered equivalent to “out of sight.”

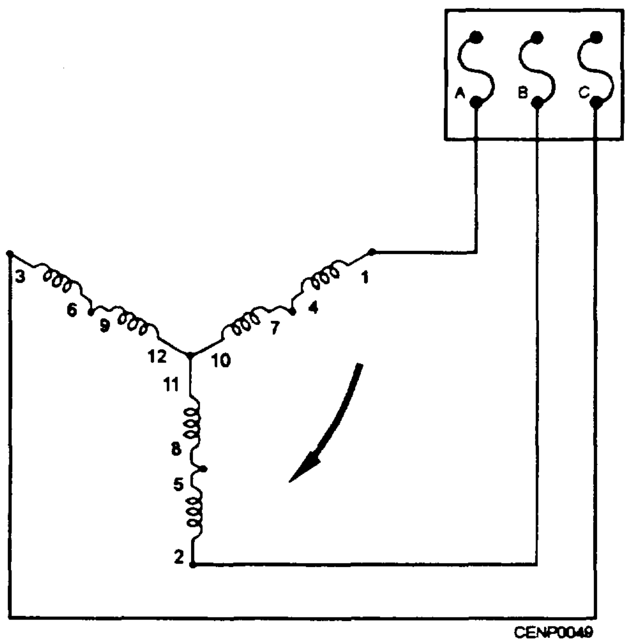


Figure 7-49.—Wye-connected motor to three-phase power for clockwise rotation.

CONTROLLER CAPABILITIES

Each controller must be capable of starting and stopping the motor which it controls and, for an alternating-current motor, it must be capable of interrupting the stalled-rotor current of the motor.

Horsepower Ratings

The controller must have a horsepower rating not lower than the horsepower rating of the motor. Exceptions are indicated below.

- For a stationary motor rated at 1/8 horsepower or less, normally left running and so constructed that it cannot be damaged by overload or failure to start (such as clock motors), the branch-circuit overcurrent device may serve as the controller.

- For a stationary motor rated at 2 horsepower or less and 300 volts or less, the controller may be a general-use switch with an ampere rating of at least twice the full-load current rating of the motor.

- For a portable motor rated at 1/3 horsepower or less, the controller may be an attachment plug connector and receptacle.

- A branch-circuit circuit breaker, rated in amperes only, may be used as a controller. Branch-circuit conductors must have an amperage capacity (ampacity) not less than 125 percent of the motor full-load current rating.

Single Controller Serving a Group of Motors

Each motor must have an individual controller, except for motors of 600 volts or less; a single controller can serve a group of motors under any one of the following conditions:

- A number of motors drive several parts of a single machine or piece of apparatus, such as a metal and woodworking machine, crane, hoist, and similar apparatus.

- A group of motors is under the protection of one overcurrent device.

- A group of motors is located in a single room within sight of the controller location.

Conductors supplying two or more motors must have an ampacity equal to the sum of the full-load current rating of all motors plus 25 percent of the highest rated motor in the group.

CONTROLLER MARKINGS

Controllers are marked with the maker's name or identification, the voltage, the current or horsepower rating, and other data as may be needed to properly indicate the motors for which it is suitable. A controller that includes motor running overcurrent protection or is suitable for group motor application is marked with the motor running overcurrent protection and the maximum branch-circuit overcurrent protection for such applications. Be extremely careful about installing unmarked controllers into any circuit. Controllers should be properly marked.

CONTROLLER CIRCUITRY

Before you condemn a motor, make sure that the fault does not lie within the controller. The only way to be sure the fault is not in the controller is to understand the circuitry of the controller. As previously mentioned, there are two general types of motor controllers: manual and magnetic.

Manual Controllers

Manual controllers (motor starters) are available up to 7 1/2 horsepower at 600 volts (three-phase) and to 3 horsepower at 220 volts (single-phase).

TOGGLE SWITCHES OR CIRCUIT BREAKERS.—A toggle switch or circuit breaker can serve as a controller, provided its ampere rating is at least twice the full-load current rating of the motor and the motor rating is 2 horsepower or less. It must be connected in a branch circuit with an overcurrent device that opens all ungrounded conductors to the switch or circuit breaker. These switches or circuit breakers may be air-brake devices operable directly by applying the hand to a lever or handle. An oil switch can be used on a circuit with a rating which does not exceed 600 volts or 100 amperes, or on a circuit exceeding this capacity, under expert supervision and by permission. A single-phase motor requires a one-element overload device,

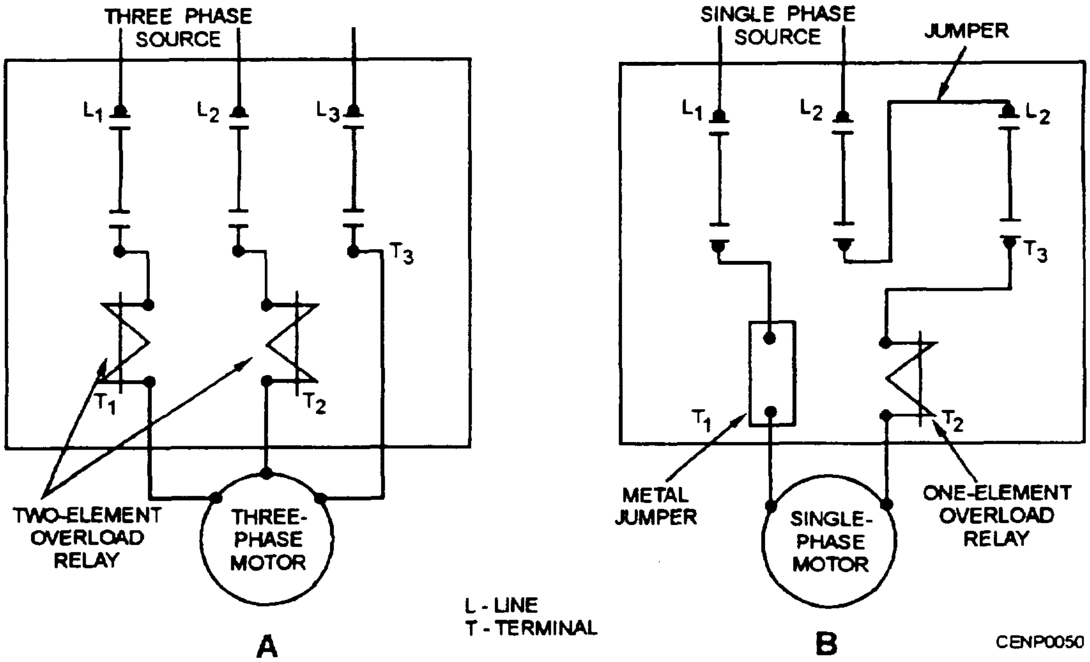


Figure 7-50.—Across-the-line manual controller.

while a polyphase motor requires a two-element overload device (fig. 7-50).

DISCONNECTS.—Disconnects may be used as controllers on motors rated up to 3 horsepower at 220 volts. They must be located within sight of the motor or be able to lock in the open position. A distance of more than 50 feet is considered "out of sight." Double-throw disconnects may be used for reversing three-phase motors if they conform to these requirements.

DRUM CONTROL.—The drum control is a lever-operated, three-position switch. The center position is usually the OFF position with the right and left positions FORWARD and REVERSE, respectively. Normally, it is used to direct the rotation of a three-phase motor. Oil-immersed drum switches are used wherever the air can become charged with corrosive gases or highly flammable dust or lint.

Magnetic Full-Voltage Starters

Magnetic starters are made to handle motors from 2 to 50 horsepower. They can be controlled by a start-stop station located locally or remotely. The starter has two different circuits: the control circuit and the load circuit.

CONTROL CIRCUIT.—The control circuit receives its power from the incoming leads to the starter. It is a series circuit (fig. 7-51) going through the start-stop station, the magnetic coil, the overload contacts, and returning to another phase. However, it may return to the ground, depending on the voltage rating of the coil.

LOAD CIRCUIT.—The current flowing through the coil activates a mechanical lever and closes the main line contacts. This closing develops the load circuit and applies power to the motor. The fourth set of contacts provides a shunt around the start button, known as the holding circuit.

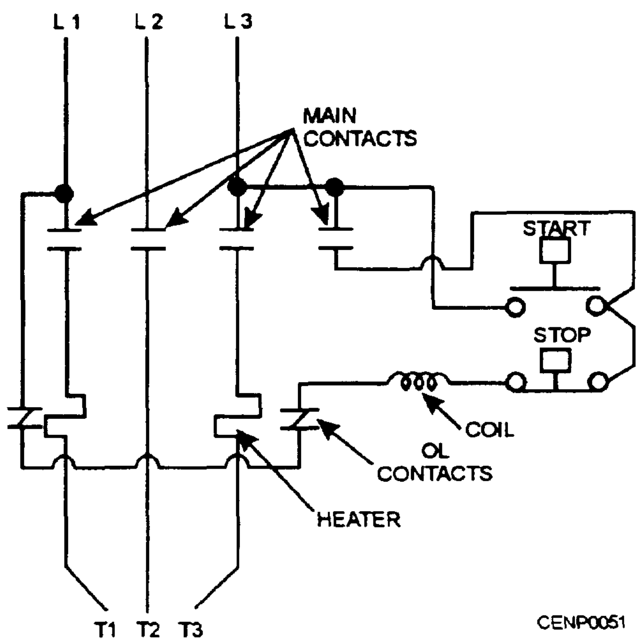


Figure 7-51.—Magnetic starter circuit.

STARTER COIL.—The coil of the starter may be de-energized in three ways. The stop button is pressed, one of the overload contacts opens, or the line voltage drops low enough to allow the coil to release. If one of these things happens, the main contacts are separated by spring pressure, removing power to the motor.

The overload contacts are opened by excess current flowing through the heater, located in the power circuit (fig. 7-51). The size of the heaters to be installed is determined by the full-load current draw to the motor. Magnetic starters are manufactured by many different companies. Information for the proper size of heater is given on the cover of the starter.

HEATERS AND HORSEPOWER.—Listed in table 7-4 is a typical horsepower and heater table for motors of different size and voltage. To determine the

Table 7-4.—Horsepower rating and heater table

Direct-Current Motors			Single-Phase AC Motors		Three-Phase AC Motors		
HP	120V	240V	115V	230V	115V	230V	460V
1/4	2.9	1.5	5.8	2.9			
1/3	3.6	1.8	7.2	3.6			
1/2	5.2	2.6	9.8	4.9	4	2	1
3/4	7.4	3.7	13.8	6.9	5.6	2.8	1.4
1	9.4	4.7	16	8	7.2	3.6	1.8
1 1/2	13.2	6.6	20	10	10.4	5.2	2.6
2	17	8.5	24	12	13.6	6.8	3.4
3	25	12.2	34	17		9.6	4.8
5	40	20	56	28		15.2	7.6
7 1/2	58	29	80	40		22	11
10	76	38	100	50		28	14

A

Heater Cat No	Trip Amps	Full Load Motor Amps Min. Max.	Max Fuse Size	Heater Cat No	Trip Amps	Full Load Motor Amps Min. Max	Max Fuse Size
42013	7.2	5.76 - 6,53	20	42022	22.4	17.9 - 19.4	80
42014	8.4	6.72 - 7.59	25	42225	25.0	20.0 - 21.8	100
42015	9.6	7.7 - 8.4	35	42226	28.0	22.4 - 24.4	100
42016	10.9	8.7 - 9.5	35	42227	32.6	26.0 - 28.3	125
42017	12.6	10.1 - 11.0	40	42228	36.3	29.0 - 31.6	125
42018	13.7	11.0 - 11.5	45	42229	42.0	33.5 - 36.5	150
42019	14.5	11.6 - 12.6	50	42230	48.0	38.4 - 41.5	150
42020	15.8	12.6 - 13.7	50	42231	52.0	41.6 - 45.2	172
42021	18.3	14.6 - 15.9	60	42232	57.0	45.5 - 49.0	200
42224	20.0	16.0 - 17.6	70	42233	60.5	49.0 - 52.5	200

B

heater number, we must know the horsepower and voltage and if the motor is single or three-phase. Once we have that information, we look at table 7-4, view A, and find the full-load motor amperage. Using the chart from table 7-4, view B, we can find the heater number for this motor. For example, we want to know the number of a heater for a 5-horsepower, 230-volt ac, single-phase motor. Checking table 7-4, view A, we find that the motor draws 28 amps. Referring to table 7-4, view B, we find heater number 42227 has an amperage range from 26.0 to 28.3. This is the heater we should use. Also in the table you will find the maximum fuse size and the amperage at which the heater will open the control circuit. Remember that each manufacturer has its own heater table to be used with its across-the-line starters.

HEATER TROUBLESHOOTING.—A heater must be manually reset at the motor starter. If the magnetic starter fails to energize, the trouble is within the control circuit. However, if the coil should energize but the motor fails to run, the trouble must be within the load circuit or motor. The load circuit can be checked at terminals TI, T2, and T3. If the proper voltage requirements is there, the trouble is most likely in the motor.

Push-Button Stations

An example of a push-button station with overload protection is shown in figure 7-52. In this case, the controller is connected to a 208-volt single-phase motor. This controller is a single-phase, double-contact device which connects or disconnects both undergrounded conductors to the motor. It has a start and stop button that mechanically opens or closes the contacts. Pressing the start button closes both contacts, and pressing the stop button opens both contacts. The control has two overload devices connected in series with the contacts. If an overload condition occurs, either overload device will open both sets of contacts. A typical application of this type control would be to control small machine tools.

Full-Voltage Reversing Starters

Reversing magnetic controllers use two magnetic across-the-line starters whose power leads are electrically interconnected to reverse two of the three phases. The two motor starters are generally contained in one box and are mechanically interlocked so that one cannot close without the other opening. They are sometimes also electrically interlocked to help prevent closing both starters at the same time.

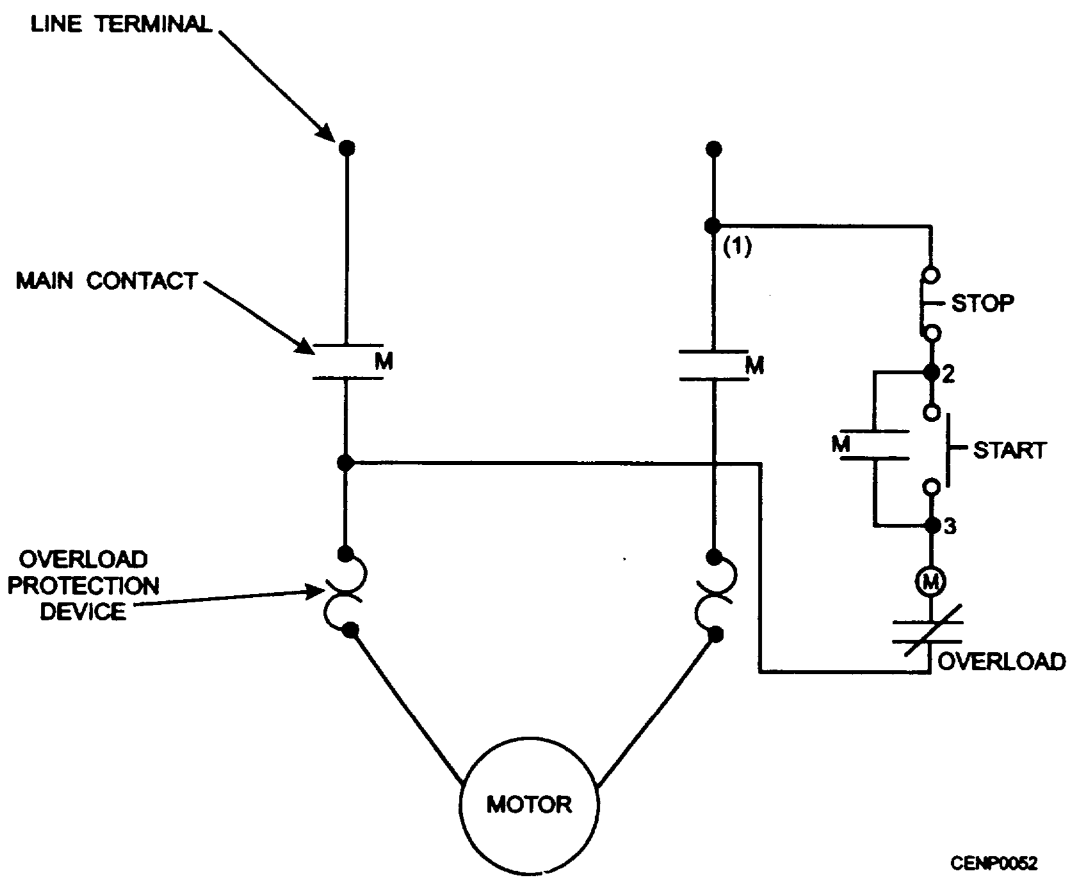


Figure 7-52.—Schematic for a single-phase manual controller with overload protection.

Reduced-Voltage Starters

Reduced-voltage starters are generally used for motors rated above 50 horsepower. Reduced-voltage starters are designed to reduce the current draw of the motor during the starting period only. They use either an autotransformer or resistor, both using the same basic principles.

Figure 7-53 is a schematic drawing of an autotransformer reduced-voltage starter. The autotransformer starter provides greater starting torque per ampere of starting current drawn from the line than any other reduced-voltage motor starter. But this type of starter is not always desirable, because, with the changing of the S and R relays, the motor is without power for a short time. Therefore, a resistance-reduced-voltage starter may be used. Resistance starters are sometimes applied where the circuit should not be opened during the transition from reduced to full voltage. They are particularly desirable when sudden mechanical shock to the driven load must be avoided.

Figure 7-54 shows a typical resistance-reduced-voltage starter. Pressing the start button energizes the S relay. The S contacts close, connecting power through the resistors to the motor. Voltage is dropped across the resistors, lowering the voltage to the motor. After a period of time, the T contact closes, energizing the R relay. The R relay contacts close, shunting around the resistors, to apply full voltage to the motor. The contact device may be a time delay relay or even a centrifugal switch, operated from the speed of the motor. Protective devices used in reduced-voltage starters are determined in the same way as we previously described.

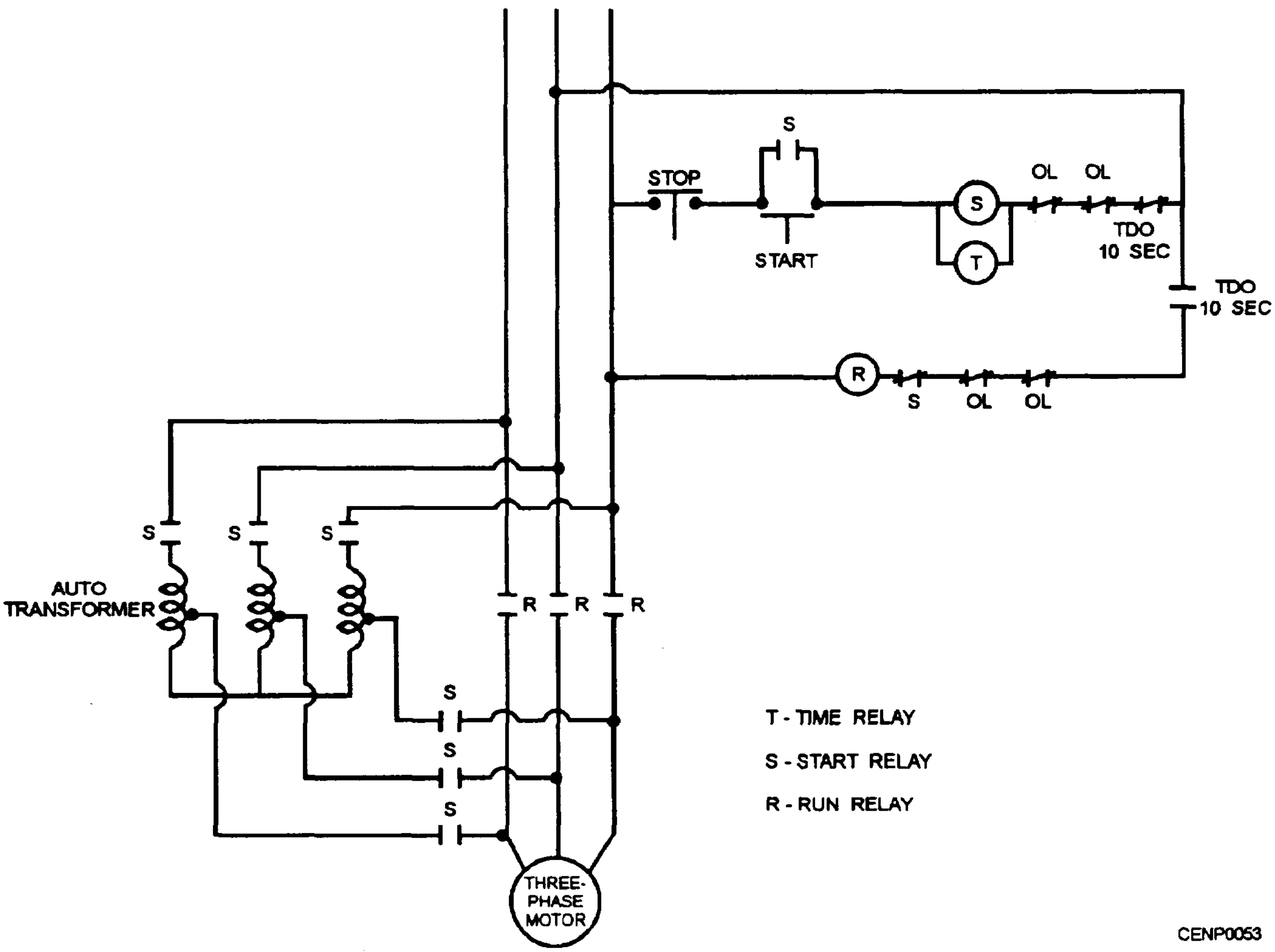


Figure 7-53.—Autotransfromer reduced-voltage starter.

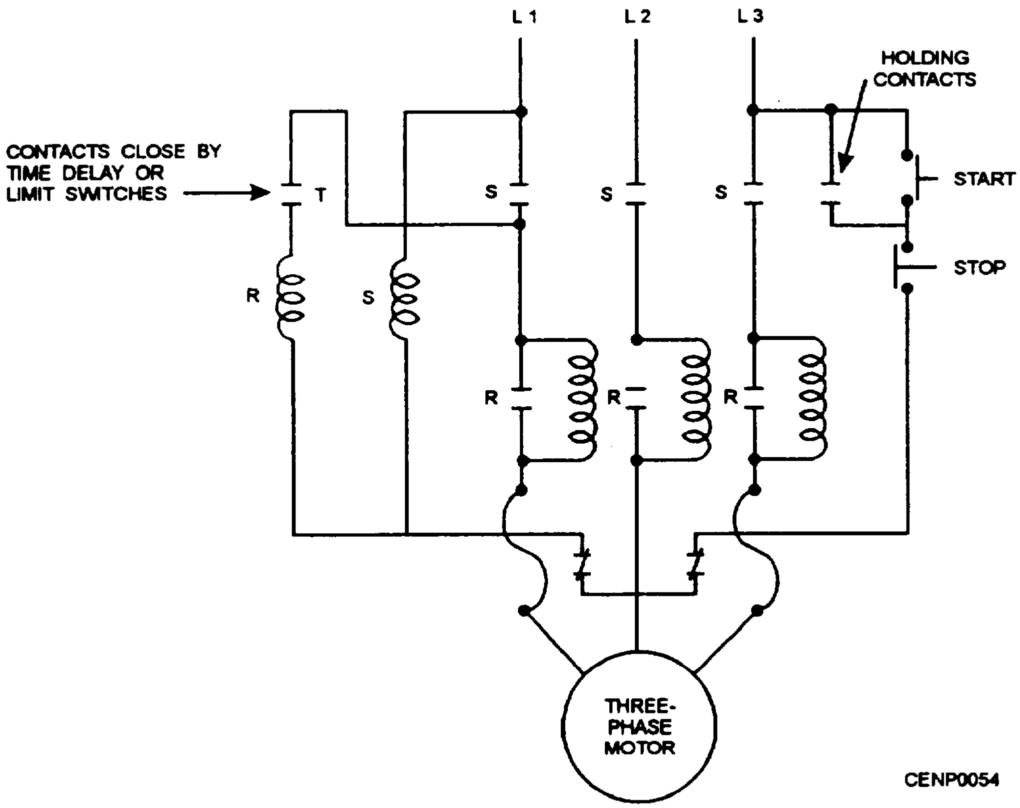


Figure 7-54.—Resistance reduced-voltage starter.

Part-Winding Starters

Part-winding starters use two magnetic starters and operate like a resistance start controller. Figure 7-55 is a schematic drawing of a wye-connected, three-phase motor. The control circuits for the S and R relays are the same as for a resistance reduced-voltage starter, and so they are not shown. The S relay is energized first, connecting voltage to only part of the winding. The motor starts to run but develops little torque. At a predetermined time, the R relay closes. This action parallels the windings in the motor, reducing their resistance and causing increased current flow and more torque.

MOTOR MAINTENANCE, TESTING, AND REPAIR

An electric motor must be checked, maintained, and repaired just like any other piece of mechanical equipment. With proper servicing, a motor will last longer and give more efficient service. Included in maintenance services are cleaning, lubrication, ventilation, and testing.

Cleaning

Inspect motors internally and externally for foreign materials, such as dust, dirt, corrosion, and paint. Open-frame motors may be blown out with compressed air. You should not apply too many coats of paint to motors. A thick coat of paint will interfere with heat dissipation.

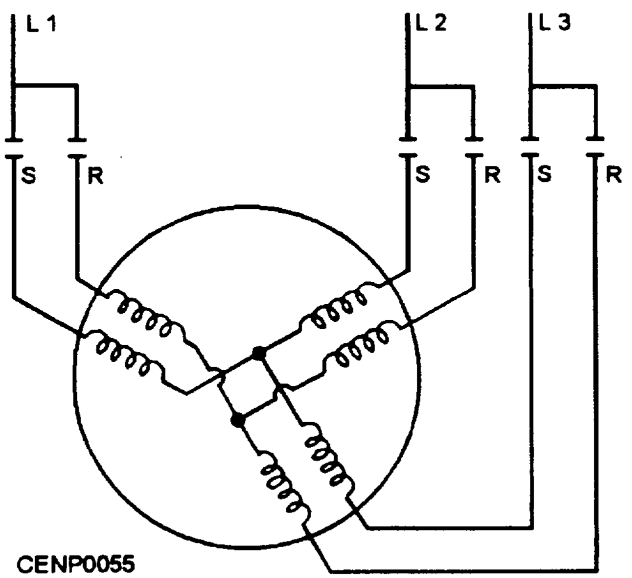


Figure 7-55.—Part-winding starter.

CAUTION

Air pressure used for cleaning should not exceed 25 psi nozzle pressure. Excessive pressure can damage the insulation on the windings.

Wipe all excess dirt, grease, and oil from the surfaces of a motor with a cloth moistened with an approved solvent.

WARNING

Do not use flammable or toxic solvents when cleaning motors. Solvents may cause injury to personnel or damage to equipment.

Lubrication

Lubrication should be done according to the manufacturer's instructions. Improper lubrication causes motor bearings to overheat and eventually causes bearing failure. Check a motor for signs of grease and oil-seal failure. If an inside seal fails, the lubricant can get into the motor windings and deteriorate the insulation. This condition also allows dust to adhere to the windings and restricts air circulation, then the motor windings heat and burn out. Inadequate lubrication causes the bearings to wear excessively and, eventually, to seize. When lubricating a motor, refer to the manufacturer's manual to determine the correct type of lubricant to use. Some motors have bearings lubricated with oil, while others require grease. Many motor bearings are lubricated and sealed at the factory and usually last the life of the bearing.

Ventilation

Check the running temperature of all motors. If the motor temperature is hotter than specified on the nameplate, you must find the problem. The normal procedure for diagnosing motor overheats is to check the motor for restricted ventilation. Inspect the area around the motor for any obstructions which could hamper free air circulation. If air circulation is not hampered in any way and the motor continues to run hot, reduce the load on the motor or use a motor with more power capability.

Testing

The proper testing of a motor should be done in a logical sequence. Proper testing can prevent unnecessary labor and parts. Testing motors is generally classed under two major methods: visual tests and operational tests.

VISUAL TESTS.—A visual test can discover a great deal about the condition of a motor and the possible causes of trouble. Read the nameplate data and be sure that the motor connections are correct for the supplied voltage.

Look at the windings to see if the insulation has overheated (or has been overheating). You can tell when the insulation is burned by the odor within the motor. If you aren't sure of the condition of the windings, test them with a megger to determine if the windings have been damaged beyond use. Connect the leads of the megger to each set of windings.

CAUTION

Disconnect the motor leads from each other to ensure reading only one winding at a time.

If the winding is good, you will get a reading of continuity. If the winding indicates a large amount of resistance, it is damaged and must be replaced.

Now connect one lead from the megger to the frame of the motor. Connect the *other* lead of the megger to each lead of the motor, one at a time. A low-resistance reading means insulation breakdown or a short to the motor frame, and replacement of the winding is necessary.

Inspect the commutator for solder thrown from the risers, and for loose, burned, high, and flat bars. Also test for high mica. Notice the surface film on both the commutators and slip rings and the general condition of the brushes. Check the air gap on large motors for any indication of bearing wear or misalignment. For large motors, take an air gap measurement at one reference point on the rotor or armature; then rotate the rotor or armature and measure four points on the stator or field frame to the same reference point. The air gap measurement should be within plus or minus 5 percent at any of these points.

Check the condition and operation of the starting rheostat in dc motors and the starting and control equipment used with ac motors. Also check the terminal connections on all of the control equipment to ensure they are correct and secure. Make sure the proper voltage is at the terminal lead of the motor.

If the visual tests have not revealed the trouble, you should perform some operational tests on the motor.

OPERATIONAL TESTS.—Perform a heat run test, observing the manufacturer's recommendations for that particular motor.

CAUTION

Do not attempt to operate a series dc motor without a load.

If the temperature of the motor in normal operation does not exceed the maximum recommended by the manufacturer, the motor is operating satisfactorily. Always refer to the manufacturer's manual for definite specifications for the motor you are inspecting.

WARNING

Be sure the master switch is in the off position before connecting or disconnecting any motor lead connections.

Because of their effect on insulating materials, high temperatures shorten the operating life of electric motors. When the windings or the bearings of a motor, not specifically designed for high temperature service, get hotter than 90 degrees centigrade, investigate the operating conditions and relieve the temperature conditions by cooling or relocating the motor. A gradually rising temperature in a motor warrants a shutdown and thorough examination of the unit. The nameplate on the motor usually specifies its normal running temperature in degrees centigrade. Check the current draw of the motor against the data on the nameplate. Excess current causes heating and, in time, will destroy the windings.

Check the motor for proper speed. A speed above or below that indicated on the nameplate signifies a malfunction in the unit. When a motor's operation is sluggish, check the line voltage to the motor. If you find the voltage low, apply the proper value and continue checking to determine if the motor is overloaded. If it is, reduce the load or replace the motor with one of a larger horsepower. There are other conditions which could make motor operation sluggish. You may find that the brushes have shifted off NEUTRAL, and you must reset them. You may also find that the armature or rotor is dragging on the stator or field poles. To correct this situation, you may need new bearings. Afield pole may be loose, causing it to drag on the armature or rotor.

Other conditions which could cause a motor to be sluggish are shorted field-winding circuits, shorted armature windings, and surface leaks across the commutator segments. After finding the fault in the motor, you may have to replace it. When you replace it, be sure to install a motor of the same size.

CAUTION

Be sure to de-energize the motor circuit before disconnecting the unit.

While the motor is running, look for any sparking at the brushes. Many faulty conditions contribute to sparking brushes at the commutator. The two major causes are a faulty armature and malfunctioning brushes. Some of the faults that could develop in an armature include the following: rough commutators, bent armature shafts, and short circuits in the armature windings. Brushes may malfunction because they are off NEUTRAL, they bind in the brush holders, they are wound beyond recommended limits, or they intermittently fail to contact the commutator because of insufficient brush spring tension. Whenever a motor is arcing at the brushes, it is advisable to disassemble it, locate the problem, and make the necessary repairs,

There are many causes of motor noise. Listen and feel for any unusual noises. You should first check the motor-mounting bolts for looseness and the alignment of the motor with the driven equipment. If the motor is secure and properly aligned, continue your inspection. Check the motor's balance. Also inspect the motor for loose rotor bars or a bent shaft. If any of these conditions exist, you will have to replace the rotor or armature. Sometimes the centrifugal switch rattles or rubs the interior of the motor housing. Align the switch and tighten the mounting bolts. If the switch has excessive wear, replace it. Check all motor accessories for looseness and tighten as needed. Check the drive pulley and the condition of the belts. Loose pulleys rattle and will damage belts. You will hear a distinct slap when the belt has been damaged.

Motor Repair

After you have performed visual and operational tests on a motor and isolated the problem, you may have to disassemble the motor to make the repairs. You should know the procedures and precautions for motor repair.

DISASSEMBLY. —The careless disassembly of a motor can cause serious damage to the delicate components within the motor. Remove and handle all parts with care and always use the proper tools. It is just as important to tag all parts, take down accurate data, and store the parts in an orderly arrangement in a safe place. Before a motor is disassembled, consider the following:

- The area for disassembly must be clean.
- Tag all leads and the point of connection from where the leads have been removed.
- Wipe all excess dirt, grease, and oil from the exterior surface with an clean cloth moistened with an approved solvent.
- Inspect all leads for burned, cracked, or deteriorated insulation at the point of their entry into the motor.
- Turn the motor shaft by hand to determine whether the armature turns freely. If not, inspect the motor for a bent shaft, misalignment of the end bells, loose or frozen bearings, a loose pole piece, or foreign objects inside the motor.

WARNING

Use gloves or a cloth to protect your hands from the sharp edges of the keyway when turning the shaft.

End Bell Removal.—When you are removing the end bells, remember that on some motors the bearings must be removed before the end bells. To remove the end bells, use the following procedure:

1. Punch mark the frame and end bells for reassembly purposes (fig. 7-56).
2. Remove the end bell fastening screws or bolts.
3. Remove the bearing first, if necessary.
4. Part the end bells from the frame, as shown in figure 7-57.
5. Record and disconnect the leads from the internal mechanism and components.
6. Clean the end bells and frame.
7. Inspect the disassembled parts and replace as needed.

Bearing Removal.—Sometimes you can remove the bearings before removing the end bells. In other cases, the bearings slip off the shafts with the end bells. Frequently, the bearings are press fitted to the shafts and end bells, making their removal difficult. Since bearing removal varies with the different types of motors, only some of the most important procedures and precautions are listed.

- Never remove bearings in good condition from the shafts or end bells unless it is absolutely necessary.
- Remove all bearing attachment screws or bolts before attempting to remove the bearings.
- Remove ball bearings which are to be reused by arbor plates and an arbor press to prevent distortion.
- Remove ball bearings to be discarded with a hook-type puller.

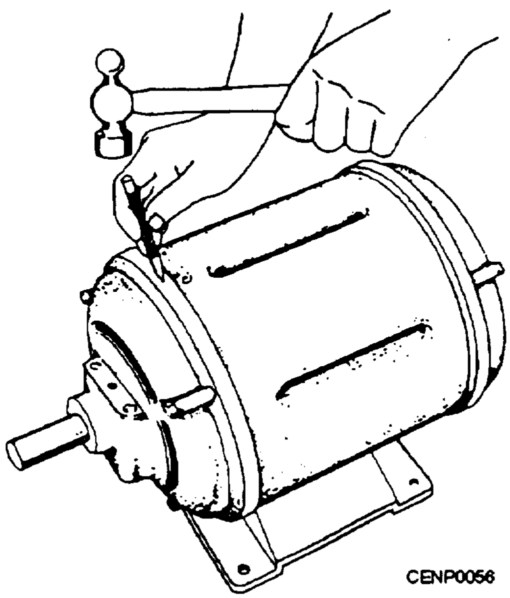


Figure 7-56.—Punch marking motor frame and end belts.

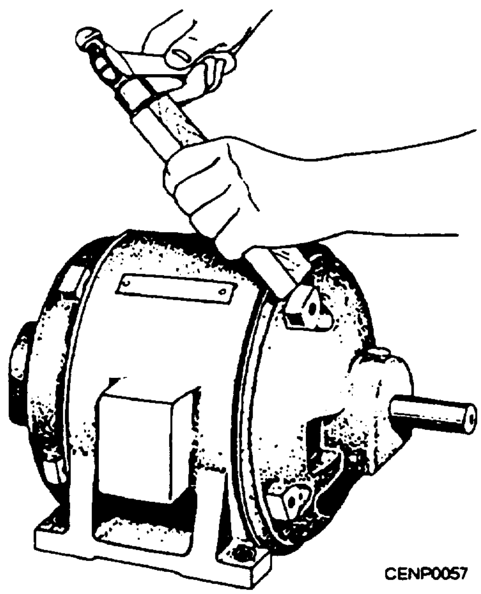


Figure 7-57.—Separating motor frame from end bells.

- Remove sleeve bearings with arbor plates and an arbor press. When an arbor press isn't available, sleeve bearings may be removed with a well-fitted arbor and hammer.

- Sometimes you may be required to remove sleeve bearings by drilling them out with a drill press.

- Handle bearings with clean, dry hands or clean canvas gloves. Handling a bearing with hands that are perspiring can cause corrosion. Fingerprint patterns are sometimes found rusted into bearing surfaces.

- Keep bearings in their packages or in oil-proof paper until they are installed

Brush Removal.—Brush removal is necessary when you are replacing brushes or you need access to parts of the unit otherwise inaccessible. If the brushes are not to be removed, place them in the raised position. Use the following procedure for removing brushes and brush rigging:

1. Record the placement and angle of brush rigging and brushes.

2. Check the brush spring pressure.

3. Remove the screws holding the brush pigtails and rigging.

4. Clean, inspect, and store the brushes and brush rigging.

Centrifugal Switch Removal.—Internal switches of the centrifugal type are usually attached to the inside of end bells. When you are removing the end bells, be careful not to break the switch springs. For removing a centrifugal switch, follow these steps:

1. Note and record the lead connections to the switch.

2. Disconnect the leads.

3. Remove the mounting screws of the stationary part of the switch which is secured to the end bell.

4. Clean and inspect the switch and replace the damaged parts.

5. Tag and store the unit.

Armature and Rotor Removal.—The removal of armatures and rotors from within the frame of the unit requires considerable care to avoid damage to the parts. For removing an armature or rotor, follow these suggestions:

1. Support the armature or rotor only by its shaft when possible.

2. Slide a thin piece of cardboard between the underside of the rotor and stator to protect the laminations and windings during rotor removal.

3. In a shop, a hoist should be used to remove the rotors of large motors.

TESTING COMPONENTS.—After a motor is disassembled, you perform certain tests to determine which components are faulty.

Field Winding.—To locate a grounded field winding, disconnect and separate the internal connections between the windings. With this done, position one lamp prod of a series test lamp to the housing. With the other test lamp prod, touch each winding lead individually. If the test lamp lights, that particular winding is grounded. Test all the windings. You may also perform this test with an ohmmeter. A reading of continuity indicates a short; no reading indicates that the field winding is not grounded.

The test for an open circuit in the field windings of a motor may also be done with a series test lamp. Touch one test lead to one coil terminal and the other lead to the opposite coil terminal. If the test lamp doesn't light, the winding is open. If it does light, an open circuit doesn't exist, and the winding is serviceable.

To test for shorts in the field winding of a motor, you can compare the relative voltage drop in each field winding section with a voltmeter. You should get the same reading for each section. A decrease in voltage drop in a section indicates a short circuit.

Armature Winding.—The first test on an armature winding should be to locate grounded circuits. This test is also performed with a series test lamp. Touch one test prod to the armature core or shaft, as shown in figure 7-58. Using the other test prod, touch each commutator segment. If the armature winding is grounded, the test lamp will light when you apply the lamp prod to the grounded armature winding or commutator segment. Replace the grounded armature when all attempts to remove the ground have failed.

When checking for a shorted armature, place the armature in an armature test set (growler). Lay the test blade lengthwise with the flat side loosely in contact with the armature core, as shown in figure 7-59. Turn the test stand to the ON position and slowly rotate the

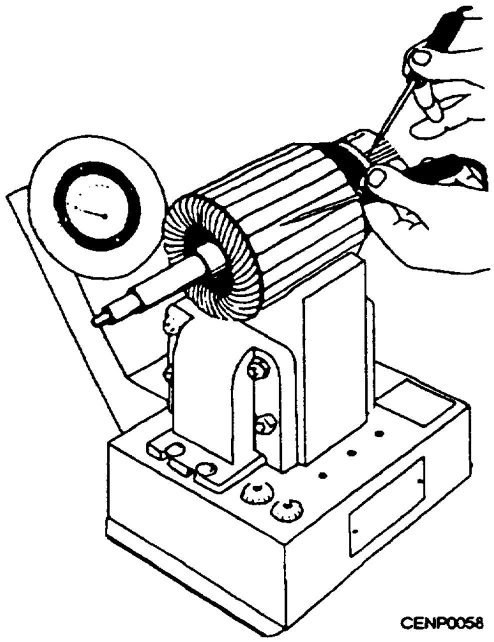


Figure 7-58.—Testing for grounds in armature windings.

armature while you hold the test blade stationary. If there is a short in the armature windings, the test blade will be attracted to the armature (magnetized) and will vibrate.

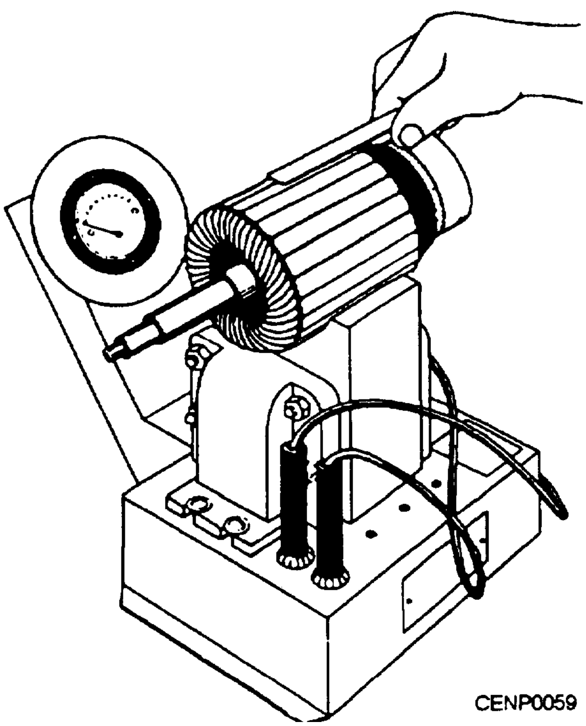


Figure 7-59.—Testing for shorts in armature windings

CAUTION

Place the test set switch in the off position before removing the armature, and never leave the test set turned on unless there is an armature placed in the core.

When you are testing an armature for an open circuit, place the armature in an armature test set and turn the test set ON. Place the armature double prods on two adjoining commutator segments and note the reading on the ammeter, as shown in figure 7-60. Rotate the armature until each pair of adjoining commutator segments have been read. All the segments should read the same. No reading indicates an open circuit, and a high reading indicates a short circuit.

CAUTION

Place the test set switch in the off position before removing the armature from the test stand.

Check the commutator for broken leads. Repair and resolder any you find. If you find an open winding, check the commutator for burned spots. They reveal the commutator segment to which the open winding is connected. Open circuits in the windings generally occur at the commutator and can be found by a visual inspection. If there is excessive sparking at the brushes with the motor reassembled, disassemble it and replace the armature.

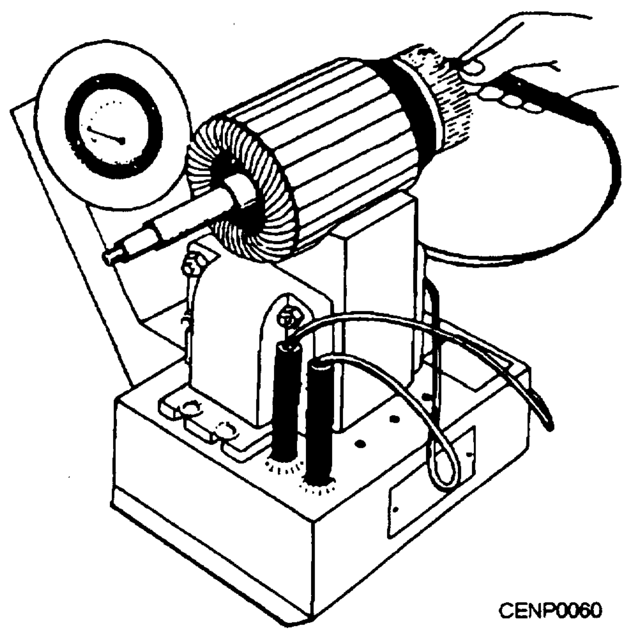


Figure 7-60.—Testing for opens in a commutator.

In testing for a grounded brush holder or rigging, touch one test lamp prod of the armature test set to the motor housing. With the other test prod, touch each brush holder individually. If the lamp lights, there is a ground in the brush holder.

CAUTION

Remove all leads to the brush holders and brushes before you attempt this test.

The color of the commutator and slip rings will indicate the type of trouble. An even chocolate-brown color indicates a normal condition and a black color indicates brush arcing. You can remove slight burns on the commutator segments by polishing the commutator as the armature rotates. Use a canvas pad, as shown in figure 7-61. To remove the deeper burns, use fine sandpaper instead of the canvas pad. When a commutator is deeply scored, it must be reconditioned in a lathe or with a special tool.

CAUTION

Never use emery cloth to polish commutators because the emery particles can lodge between the segments and cause the commutator circuits to short.

Slip rings used on rotors are usually made of bronze or other nonferrous metals. Under normal conditions, the wearing surface should be bright and smooth. When the rings are pitted, they should be polished. When excessively worn and eccentric, they should be trued with a special tool.

REASSEMBLY.—After you have inspected all parts and repaired or replaced the faulty ones, you are ready for reassembly. To assemble motors, follow in reverse order the procedures of their disassembly. Be sure to check any available literature you may find. Be sure to oil or grease the bearings as required. Remove the relief plug in the bottom of the housing while you apply grease.

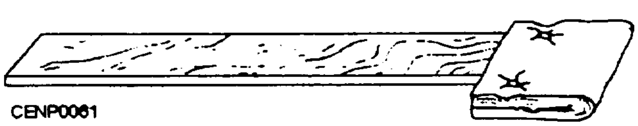


Figure 7-61.—Fabricated cleaning pad.

MOTOR CONTROLLER MAINTENANCE AND REPAIR

The most important rule to remember when you are making repairs or inspecting motor controllers is as follows:

CAUTION

Be sure the controller is disconnected from the power source before touching any of the operating parts.

Control equipment should be inspected and serviced on the same maintenance schedule as motors. Motor starters can normally be repaired on the job site at the time of inspection. After the power has been secured, the first thing you should do to keep controllers operating at maximum efficiency is to keep them free of dirt, dust, grease, and oil, both inside and out. Clean the operating mechanism and contacts with a clean, dry, tintless cloth, or vacuum cleaner. Small and delicate mechanical parts may be cleaned with a small, stiff bristle brush and a Navy-approved solvent.

Check the contacts to ensure proper electrical connections. When contacts open and close, the rolling and rubbing action keeps the contacts bright and clean. Infrequently operated contacts or contacts under heavy loads can overheat and create oxidation on the contacts.

Copper Contacts

Copper contacts are used for most heavy-duty power circuits, and, in many cases, in relay and interlock circuits. They should be inspected regularly. If projections extend beyond the contact surfaces or if the contacts are pitted or coated with copper oxide, they should be sanded down with fine sandpaper.

Welding of contacts sometimes occurs, in spite of all precautions. Low voltage is the most common cause. Welding may also result from overloads, low-contact pressure resulting from wear or weak springs, loose connections, or excessive vibrations. If welding occurs, it is an indication of trouble in the electrical system. The contacts must be replaced, but it is useless to replace them unless the cause of the welding is found and corrected.

Carbon Contacts

Carbon contacts are used when a contactor is frequently opened and closed. It is essential that the contactor be open when it is de-energized. Since carbon contacts will not weld together when closed, they are better than metal contacts for ensuring that a de-energized contact is open. However, carbon contacts are used only when necessary. Because the current capacity of carbon per square inch of contact surface is very low, the contacts made of carbon must be relatively large.

Silver Contacts

Silver contacts are used extensively in pilot and control circuits, on relays, interlocks, master switches, and so on. They are used also on smaller controllers and on heavy-duty equipment where the contactors remain closed for long periods of time with infrequent operation. Silver contacts are used because they ensure better contact than other less expensive material.

Pure silver contacts and silver-cadmium-oxide contacts should not be replaced until they become too worn to give good service. Their appearance will indicate when they are worn to such an extent that they are no longer serviceable (fig. 7-62).

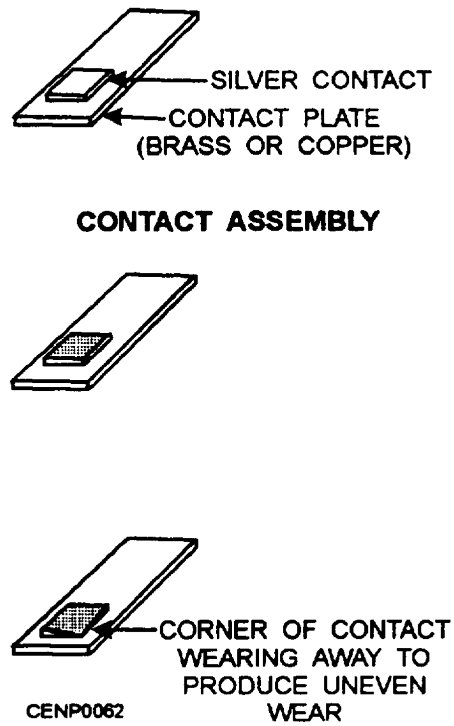


Figure 7-62.—Silver contacts.

ELECTRICAL AND MECHANICAL WEAR.—Normally, contacts are subjected to electrical and mechanical wear as they establish and interrupt electric currents. Electrical wear is usually greater than mechanical wear. If a movable contact assembly has no appreciable sliding action on its associated stationary contact assemblies, mechanical wear will be insignificant.

Electrical wear or erosion is caused by arcing when the contacts are establishing and interrupting currents. During arcing, a small part of each contact is melted, vaporized, and blown away from the contact. As a pure silver contact erodes, its arcing surface changes in color, contour, and smoothness. Figure 7-62 shows typical changes in contour and smoothness.

Normally, a new contact has a uniform silver color, a regular contour, and a smooth arcing surface. As the contact wears, discolorations usually give it a mottled appearance, showing silver, blue, brown, and black. The black color comes from the silver oxide formed during arcing. Silver oxide is beneficial to the operation of the contact.

Electrical erosion may cause uneven wear of the contacts and consequent contour irregularity. Uneven contact wear doesn't necessarily indicate that the contact should be replaced Manufacturers usually provide a total thickness of silver equal to twice the wear allowance associated with the contact to allow for uneven contact wear.

Melting and vaporization of contacts cause pitting of the arcing surface. The pitted surface has high spots which are quite small in area. Tests indicate that such a surface is better than a surface which has not been subjected to arcing because its circuit-making reliability is improved.

A silver-cadmium-oxide contact shows the same wear characteristics as a pure silver contact, except that small black granules may be evident on the arcing surface. These granules are cadmium oxide, a black material which is scattered throughout the mixture that has formed on the contacts. Silver oxide is formed during arcing, just as with a pure silver contact. The addition of cadmium oxide greatly improves contact operation because it minimizes the tendency of the contacts to weld together, retards heavy transfer of material from one contact to the other, and inhibits erosion.

WEAR ALLOWANCE.—A contact is service as long as its wear allowance, and its associated contacts, exceeds the minimum value specified by the manufacturer. (Usually the minimum value is 0.015 to 0.030 inch). The "wear allowance" of contacts is defined as the total thickness of contact material which may be worn away before the contact of two associated surfaces becomes inadequate to carry rated current.

In an electric-motor contactor, the wear allowance of the power pole contacts is usually related to the closed position of the magnetic operator. The wear allowance of the power pole contacts of a magnetic contactor is the amount of silver that can be worn away without resulting in failure of the contacts to touch when the magnetic operator is at its closed position.

Blowout Coils

Blowout coils seldom wear out or give trouble when used within their rating. However, if they are required to carry excessive currents, the insulation becomes charred and fails, causing flashovers and failure of the device.

Arc shields are constantly subjected to the intense heat of arcing and may eventually burn away, allowing the arc to short-circuit to the metal blowout pole pieces. Therefore, arc shields should be inspected regularly and renewed before they burn through.

Arc barriers provide insulation between electrical circuits and must be replaced if broken or burned to a degree where short circuits are likely to occur.

The importance of having clean, tight electrical connections must be emphasized. Where practical, it is a good idea and common practice to solder electrical connections.

Excessive slamming on closing, particularly on ac magnetic-operated devices, will eventually damage the laminated face of the magnetic armature and may damage the shading coil.

Magnetic coils should be kept dry. Wet coils should always be dried out before using. They may be dried by baking them in a well-vented oven at not more than 194°F to prevent water from boiling in the insulation. The length of time in the oven depends on the size of the coil. If an oven isn't available, place the unit under a canvas cover roomy enough for hot air to be circulated within. Another alternative is to direct infrared lamps on the windings.

The closed pressure of contacts is an important factor in their ability to carry current. A small contact with proper contact pressure carries more current than a large one with little pressure. Contact springs must be kept in condition. Replace them when they have been damaged or have lost temper by exposure to high temperatures.

Connections should always be clean and tight. Loose connections result in overheated parts that eventually need replacing. Periodic inspections are necessary because temperature changes, vibration, and carelessness may loosen the connections.

Inspect the movable core of a controller for cleanliness. Accumulated dirt causes sluggish mechanical action which impairs the opening and closing of the contact.

Noise results if the movable and stationary pole pieces don't fit together well when the contactor is closed or when dirt or rust prevents proper closure. The most prominent noise produced in a controller comes from a broken shaded pole, which is a single turn of wire or strap, imbedded in part of the laminated magnetic structure.

Check the cabinet which houses the controller for cleanliness. Make sure the cover fits properly to keep moisture, dirt, and dust from entering. Check for corrosion of all metal parts. Table 7-5 is a guide for troubleshooting ac controllers.

Table 7-5.—Troubleshooting chart lor alternating-current controllers

Trouble	Probable cause	Remedy
Failure to close	No power.	Check power source. Replace faulty fuses.
	Low voltage.	Check power-supply voltage. Apply correct voltage. Check for low power factor.
	Inadequate lead wires.	Install lead wires of proper size.
	Loose connections.	lighten all connections.
	Open connections and broken wiring.	Locate opens and repair or replace wiring. Remove dirt from controller contacts.
	Contacts affected by long idleness or high operating temperature.	Clean and adjust.
	Contacts affected by chemical fumes or salty atmosphere.	Replace with oil-immersed contacts.
	Inadequate contact pressure.	Replace contacts and adjust spring tension.
	Open circuit breaker.	Check circuit wiring for possible fault.
	Defective coil.	Replace with new coil.
	Overload-relay contact latched open.	Operate hand- or electric-reset.
Failure to open	Interlock does not open circuit.	Check control-circuit wiring for possible fault. Test and repair.
	Holding circuit grounded.	Test and repair or replace grounded parts.
	Misalignment of parts; contacts apparently held together by residual magnetism.	Realign and test for free movement by hand. Magnetic sticking rarely occurs unless caused by excessive mechanical friction or misalignment of moving parts. Wipe off pole faces to remove accumulation of oil.
	Contacts welded together.	See CONTACTS WELDED TOGETHER section.
Sluggish Operation	Spring tension too strong.	Adjust for proper spring tension.
	Low voltage.	Check power-supply voltage. Apply correct voltage.
	Operating in wrong position.	Remount in correct operating position.
	Excessive friction.	Realign and test for free movement by hand. Clean pivots.
	Rusty parts due to long periods of idleness.	Clean or renew rusty parts.

Table 7-5.—Troubleshooting chart for alternating-current controllers—Continued

Trouble	Probable cause	Remedy
Sluggish Operation (Continued)	Sticky moving parts.	Wipe off all accumulations of oil and dirt. Bearings do not need lubrication.
	Misalignment of parts.	Check for proper alignment. Realign tc reduce friction and test for free movement by hand.
Erratic Operation (Unwanted Openings and Closures and Failure of Overload Protection)	Short circuits.	Test and repair or replace defective parts.
	Grounds.	Test and repair or replace defective parts.
	Sneak currents.	These are usually caused by intermittent grounds or short circuits in the machines or wiring circuit. Test and replace faulty parts or wiring.
	Loose connections.	Tighten all connections. Eliminate any vibrations or rapid temperature changes that may occur in close proximity to the controller.
Overheating of Coils	Shorted coil.	Replace coil.
	High ambient temperature or poor ventilation.	Relocate controller, use forced ventilation or replace with suitable type controller.
	High voltage.	Check for shorted control resistor. Check power-supply voltage. Apply correct voltage.
	High current.	Check current rating of controller. Make check for high voltage above. If necessary, replace with suitable type controller.
	Loose connections.	Tighten all connections. Check for undue vibrations in vicinity.
	Excessive collection of dirt and grime.	Clean but do not reoil parts. If covers dc not fit tightly, realign and adjust fasteners.
	High humidity, extremely dirty atmosphere, excessive condensation, and rapid temperature changes.	Use oil-immersed controller or dusttight enclosures.
	Operating on wrong frequency.	Replace with coil or proper frequency rating.

Table 7-5.—Troubleshooting chart for alternating-current controllers—Continued

Trouble	Probable cause	Remedy
Overheating of Coils Continued)	D-c instead of a-c coil.	Replace with a-c coil.
	Too frequent operation.	Adjust to apply larger control.
	Open armature gap.	Adjust spring tension. Eliminate excessive friction or remove any blocking in gap.
Contacts Welded Together	Improper application.	Check load conditions and replace with a more suitable type controller.
	Excessive temperature.	Smooth off contact surface to remove concentrated hot spots.
	Excessive binding of contact tip upon closing.	Adjust spring pressure.
	Contacts close without enough spring pressure.	Replace worn contacts. Adjust or replace weak springs. Check armature overtravel.
	Sluggish operation.	See SLUGGISH OPERATION.
	Rapid, momentary, touching of contacts without enough pressure.	Smooth contacts. Adjust weak springs. Where controller has JOG or INCH control button, operate this less rapidly.
Overheating of Contacts	Inadequate spring pressure.	Replace worn contacts. Adjust or replace weak springs.
	Contacts overloaded	Check load data with controller rating. Replace with correct size contactor.
	Dirty Contacts.	Clean and smooth contacts.
	High humidity, extremely dirty atmosphere, excessive condensation, and rapid temperature changes.	See OVERHEATING OF COILS.
	High ambient temperature or poor ventilation.	See OVERHEATING OF COILS.
	Chronic arcing.	Adjust or replace arc chutes. If arcing persists, replace with a more suitable controller.
	Rough contact surfaces.	Clean and smooth contacts. Check alignment.
	Continuous vibration when contacts are closed.	Change or improve mounting of controller.
	Oxidation of contacts.	Keep clean, reduce excessive temperature, or use oil-immersed contacts.

Table 7-5.—Troubleshooting chart for alternating-current controllers—Continued

Trouble	Probable cause	Remedy
Arcing at Contacts	Arc not confined to proper path.	Adjust or renew arc chutes. If arcing persists, replace with more suitable controller.
	Inadequate spring pressure.	Replace worn contacts. Adjust or replace weak springs.
	Slow in opening.	Remove excessive friction. Adjust spring tension. Renew weak springs. See SLUGGISH OPERATION.
	Faulty blowout coil or connection.	Check and replace coil. Tighten connection.
	Excessive inductance in load circuit.	Adjust load or replace with more suitable controller.
Pitting or Corroding of Contacts	Too little surface contact.	Clean contacts and adjust springs.
	Service too severe.	Check load conditions and replace with more suitable controller.
	Corrosive atmosphere.	Use airtight enclosure. In extreme cases, use oil-immersed contacts.
	Continuous vibration when contacts are closed.	Change or improve mounting of controller.
	Oxidation of contacts.	Keep clean, reduce excessive temperature, or use oil-immersed contacts.
Noisy Operation (Hum or Chatter)	Poor fit at pole face.	Realign and adjust pole faces.
	Broken or defective shading coil.	Replace coil.
	Loose coil.	Check coil. If correct size, shim coil until tight.
	Worn parts.	Replace with new parts.
Vibration after Repairs	Misalignment of parts.	Realign parts and test for free movement by hand.
	Loose mounting.	Tighten mounting bolts.
	Incorrect coil.	Replace with proper coil.
	Too much play in moving parts.	Shim parts for proper tightness, and clearance.